Uniwersytet Przyrodniczy we Wrocławiu
Wydział Biotechnologii i Nauk o Żywności
Dyscyplina naukowa: Technologia żywności i żywienia

MRES Charles Odilichukwu R. OKPALA

Wpływ procesu marynowania na jakość mięsa w kontekście znaczenia zarządzania jakością w sektorze rolno-spożywczym

The effect of marination process on meat quality in relation to the relevance of quality management in the agrifood sector

Rozprawa doktorska

Promotor: dr hab. inż. Małgorzata Korzeniowska, prof. uczelni

Drugi Promotor: Prof. dr hab. inż. Raquel P. F. Guiné

Wrocław 2023

Summary (English)

The quality of meat products, as revealed by characteristic attributes, is sustained by appropriate safety levels/standards within the (meat) technological process. The use of marination processes combined with thermal preservation prospects should be alternatives that enhance meat product quality. Personnel's knowledge of quality and its utilization for the meat stakeholders' supply chain is crucial. This current work, therefore, performed the enhancement of marinated oven grilled meat processing in relation to the relevance of quality management in the agrifood sector. Research methodology involved relevant literature synthesis, which provided gaps that were filled by experimental activities supplemented by field surveys. The experimental activities involved the combined application of three level marination variants (concentration increments of 0.5, 1, and 1.5% by volume based on gram/mL) and fixed oven-grill process parameters (temperature = 180°C; time = 5 min) to beef entrecôte, chicken breast and pork neck meat products, followed by evaluation of resultant quality attributes. Chemical attributes involved antioxidant capacity (ABTS, DPPH), ferric reducing antioxidant power (FRAP), pH, changes in thiobarbituric acid reactive substance (TBARS). Physical attributes involved cooking weight loss, L*a*b* color coordinates, and textural cutting force. Organoleptic attributes involved sensory (appearance, flavour, taste, and tenderness), as well as, texture (chewiness, gumminess, graininess, greasiness, and hardness) components. Marinated oven-grill meat processing can be enhanced when applied to different meat products, namely, chicken breast, beef entrecote, as well as pork neck, obtained distinct ranges/trends specific to chemical and physical attributes, i.e., antioxidant, pH, lipid breakdown, color and texture. However, to establish a collective organoleptic (sensory and texture) trend proved challenging given the statistical resemblances, as well as fluctuations. Marinated oven-grill meat processing promises to moderate the range values of key quality attributes of the chicken breast, beef entrecote, and pork neck products. Considering both conducted field surveys and marinated oven-grilled meat experimentation, there are relation points of quality assurance/management. Meat stakeholders deliver the quality management in agro food industry as shown by butchers that possess good hygiene and storage practices, and food retail managers/supervisors that utilize the good practices to facilitate the identification of cleaner production components, and enhance the environmental awareness of consumers/customers. Using the context of food retail, a definition of 'cleaner food production 'was suggested, which is: "*the effective and efficient utilization of good practices to deliver high quality food retail products through environmental-friendly as well as sustainable processes*".

Key words: quality, meat marination processes, quality management, oven-grilling, knowledge transfer, product development

Streszczenie

Jakość wyrobów mięsnych, opisana charakterystycznymi cechami, utrzymywana jest zgodnie z zapisami odpowiednich norm bezpieczeństwa w ramach procesu technologicznego (mięsa). Zastosowanie procesu marynowania w połączeniu z obróbką termiczną może stanowić alternatywę dla poprawy jakości produktów mięsnych. Ponadto, wiedza personelu na temat jakości i jej kształtowania ma kluczowe znaczenie w całym łańcuchu dostaw żywności w tym mięsa. W związku z tym celem niniejszej pracy było doskonalenie operacji marynowanego mięsa do obróbki termicznej na grillu w odniesieniu do znaczenia zarządzania jakością w sektorze rolno-spożywczym. Metodologia badań obejmowała syntezę dostępnych danych literaturowych ze wskazaniem luk, które zostały uzupełnione wynikami badań eksperymentalnych uzupełnionymi wynikami badań terenowych. W części eksperymentalnej zastosowano trzy warianty marynowania (dodatek marynaty w ilości 0,5%, 1,0% i 1,5%) przy ustalonych parametrach procesu grillowania w piekarniku (temperatura 180°C; czas 5 min). Materiałem badawczym był antrykot wołowy, pierś kurczęca i karkówka wieprzowa. Po obróbce termicznej wykonano ocenę wybranych cech jakości mięsa, która obejmowała m. in. analizę właściwości przeciwutleniających (ABTS i DPPH), zdolność do redukcji żelaza (FRAP) i pH oraz stabilność przechowalniczą testem z kwasem tiobarbiturowym (TBARS). Cechy fizyczne próbek analizowana za pomocą pomiaru utraty masy po obróbce termicznej, koordynatów barwy L*a*b* i siły cięcia. Mięso poddano także ocenie organoleptycznej wyglądu, zapachu, smaku i kruchości oraz konsystencji (żuwalności, gumowatości, ziarnistości, odczucia tłustości i twardości). Na podstawie uzyskanych wyników można stwierdzić, że technologia marynowania mięsa do grillowania może zostać udoskonalona w odniesieniu do konkretnych produktów mięsnych i ich cech jakościowych, tj. barwa i tekstura.

Jednakże, uzyskanie zbieżnych wyników w ocenie organoleptycznej (ogólna ocena sensoryczna i konsystencji) okazało się trudne w realizacji, biorąc pod uwagę istotność statystyczną, a także odchylenie standardowe wyników. Proces marynowania mięsa na grilla wpływa na polepszenie wartości zakresów kluczowych cech jakościowych piersi kurczęcej, antrykotu wołowego, a także karkówki wieprzowej. Biorąc pod uwagę zarówno wyniki części badawczej dotyczącej marynowania mięsa z przeznaczeniem do obróbki grillowej, jak i przeprowadzone badania ankietowe, można wskazać pewne obszary, w których zapewnienie jakości/zarządzanie jakością jest niezbędne w całym systemie produkcji żywności. W szczególności wyniki uzyskiwane w badaniach laboratoryjnych są ściśle powiązane z zarządzaniem jakością w przemyśle rolno-spożywczym, co wykazano w badaniach terenowych w wyniku przeprowadzonej ankietyzacji, w których rzeźnicy wyraźnie przyjęliby dobre praktyki w zakresie higieny i przechowywania mięsa, a kierownicy/managerowie sprzedaży detalicznej żywności wykorzystaliby dobre praktyki w celu ułatwienia identyfikacji czystszych komponentów do produkcji i zwiększenia świadomości ekologicznej konsumentów/klientów. Korzystając z kontekstu sprzedaży detalicznej żywności, zaproponowano definicję „czystszej produkcji żywności", która brzmi: *„skuteczne i efektywne wykorzystanie dobrych praktyk w celu detalicznego dostarczania żywności wysokiej jakości poprzez przyjazne dla środowiska i zrównoważone procesy"*.

Słowa kluczowe: jakość, proces marynowania mięsa, zarządzanie jakością, grillowanie, transfer wiedzy, rozwój produktu

Table of content

Acknowledgments

First and foremost, all praise and thanks to Almighty Jehovah for life, health, and capacity throughout this doctoral journey. Secondly, thanks to Wrocław University of Environmental and Life Sciences, Poland (UPWr) for financing this doctoral program, and inscribing my name in this citadel.

Thank you prof dr hab Małgorzata Korzeniowska for your formidable and unwavering commitment towards this work's success. Thank you prof dr hab. Raquel P.F. Guiné for your painstaking and useful insights, which added very great value.

Mgrs Szymon Juchniewicz, Katarzyna Leicht, Hanna Skendrović, and Mouandhe Imamou Hassani, your various roles to enhance the success of this work is highly appreciated.

Department of Functional Food Products Development, alongside International Relations Office - UPWr, thank you for your very great efforts. To the University of Georgia Cooperative Extension, especially my senior colleagues at Northeast District+ Richmond, I appreciate your encouragement.

My widowed mum, Julie, and my brothers, Nnaemeka, Chibuzo, Uchenna, and Amala, your unwavering prayers were invaluable.

God's blessings and protection to everyone

Charles Odilichukwu R. OKPALA
MRES(Strath.), CSci, FIFST (UK) MIAFP, MIFT, CFS (USA)

List of published works

a) Review of relevant literature to establish the knowledge gaps

1. Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (*Accepted for publication*).Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. *Food Sci. Technol. (Campinas).*
   IF (2022)= 1.718 (Q3), Ministerial points= 40

2. Okpala, C. O. R., & Korzeniowska, M. (2020). Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. *Front. Nutr.* 7, 578941.
   IF (2022)= 6.590 (Q1), Ministerial points= 70

3. Okpala, C. O. R., & Korzeniowska, M. (2023). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. *Food Rev. Int.* 39(4) 1879-1952.
   IF (2022)= 6.043 (Q1), Ministerial points= 100

b) Experimental and survey papers, which contributes to filling some knowledge gaps

4. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F.(2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. *Foods* 11(24), 3951.

   IF (2022)= 5.561 (Q1), Ministerial points= 100

5. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023a). Quality attributes of different marinated oven-grilled pork neck meat. *Int. J. Food Prop.* 26(1), 453-470.

   IF (2022)= 3.388 (Q2), Ministerial points= 70

6. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023b). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. *PeerJ* 11, e15116

   IF (2022)= 3.06 (Q1), Ministerial points= 100

7. Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021). Assessing Nigerian Butchers ' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods* 10(6), 1165.

   IF (2022)= 5.561 (Q1), Ministerial points= 100

8. Okpala, C. O. R. (2023). Good Practices contributing to Cleaner Food Production? A Preliminary Survey Analysis involving Wrocław-Poland Food Retail Sector. *Processes* 11(4), 1224.

IF (2022)= 3.352 (Q2), Ministerial points= 40

Executive summary of doctoral thesis

1) Introduction:

- Quality as a principal player in the agrifood industry
- Assuring and managing quality applicable to meat process technology
- Towards achieving optimization of meat products using marination preservation prospects

2) Research hypothesis/ problem statement

3) Overall aim, and specific objectives of the study

4) Research methodology

- Steps followed to conduct the review of relevant literature
    - Steps followed to conduct the experimental studies involving the formulation of different meat products, and the evaluation of quality attributes
    - Steps followed to conduct the field surveys involving meat industry and associated stakeholders

5) Reflections on published works

- Review relevant literature, from how quality of animal meat products are enhanced by combining plant-based marinations and thermal processes, to what makes quality management relevant in the agrifood sector;
- Experimental studies, in order to evaluate: i) the effect of various marination receipts on the culinary quality of different meat types including chicken breast, pork

neck and beef entrecôte; ii) the effect of grilling process on the physicochemical properties, antioxidant power and sensorial acceptability;

- Field studies, which surveyed supply chain stakeholders associated with the meat industry, specifically butchers as well as food retail managers/supervisors, and relate with their knowledge of quality and its utilization.

6) Summary and recommendation for future studies

1) Introduction

a) Quality as a principal player in the agrifood industry

Quality, neither perceived as scientific/technical expression nor as physical entity on one hand, occupies a fixed position within the common space of either space and or time(Bremner, 2000; Okpala & Korzeniowska, 2020, and 2023). Quality, proffered as a very useful idea on the other hand, remains utilized within the common space of life and management (Bremner, 2000; Okpala & Korzeniowska, 2020 and 2023). Therefore, when quality and its qualifying components are debated across the agrifood technology, it reflects the characteristics anticipated of given product (or service). Given this premise, holistically and regardless of location, quality of a given agrifood product should possess some ability to meet the demands/needs of consumers across communities (Kohls and Uhl, 2015). Further, quality is among the essential objectives continually sought after by the agrifood industry (Vasconcellos, 2004; Okpala & Korzeniowska, 2020 and 2023). Earlier workers (Goodman, 2003; Ilbery and Kneafsey, 2000; Lopez and Martin, 2006) had assigned quality (applicable to agrifood products) with three distinct perspectives, namely:(a) the institutional perspective, which comprised objective and regulated indicators that help to define the quality largely based on hygiene requirements; (b) the consumer perspective, which is underpinned by the premise that quality is based on the experience acquired over a given time period specific to the dimensions of risk and trust; and (c) the producers 'perspective, which is underpinned by the combined efforts of raw materials and production methods that eventually help to define the quality attributes.

As an essential component of any economic activity, quality within the agrifood industry impacts either directly or indirectly on consumer, producer, and product/service (Gheorghe, 2012). It can be assumed that the overall quality of the same agrifood product, when comparing on one market shelf to another, may likely not be exactly the same, which would largely consider both internal and external factors influencing (agrifood) production (Bruntrup et al., 2013; Vasconcellos, 2004). Such quality differences in agrifood products at the various market shelves are likely to underscore the challenges that emanate from how certification standards are generated and revealed (Okpala & Korzeniowska, 2023; Dequiedt, 2020; Vasconcellos, 2004). Considering any given agrifood product, moreover, some perspectives could associate with how one or more situations influence its overall quality (Okpala & Korzeniowska, 2020; Vasconcellos, 2004). Besides, Juran (1994) argued that the defect-free characteristics exhibited in a given product quality would help to avoid consumer dissatisfaction. Probably, the viewpoint consumers would have about the quality of the same agrifood product obtained from one specific agrifood industry should like vary. Thus, quality framework associated with a given agrifood process should depend on such factors as capacity of service delivery, capital/cost, enterprise size, expertise/skillset, labor/manpower, as well as type of good transacted (Fałkowski, Curzi & Olper, 2019). Hence, the success of the quality framework in the agrifood industry would depend on the effective and efficient working of all the above-mentioned factors.

b) Assuring and managing quality applicable to meat process technology

Despite the complexities the underpin the agrifood supply chain, the initiation, implementation and sustenance of quality remains crucial. Regardless of the location, to prepare food to the right hygienic standards, there has to be the appropriate knowledge that produces effective food-handling skills. To achieve this, there has to be the right motivation to act on that knowledge. The required level of food safety knowledge can only be attained by fortified education that is validly proven with reliable instruments (Medeiros et al., 2001 and 2004). However, implementing as well as practicing food safety knowledge remains very relative as it would differ from person to person, place to place, as well as scenario to scenario, despite the adherence to existing framework/standards. For instance, regards person-to-person, the food safety knowledge of food service personnel in a typical restaurant with diverse menus would differ (Kennedy et al., 2005; Mihalache et al., 2021). The basic foundation for foodservice is underpinned by good practices, which serve as the backbone of quality within the meat industry (Okpala et al., 2022a; Okpala & Korzeniowska, 2023). Indeed, good practices cut across all key aspects of the supply chain processes found within the (agro)food industry (Varzakas and Tzia, 2016). When the job roles of all who deliver quality within the food industry/sector are not clearly defined as well as understood, the integrity of food safety would be compromised. There is a need, therefore, to reiterate the importance of good practices in the domain of food quality and consumer protection (Raspor and Jevšnik, 2008; Varzakas and Tzia, 2016; Okpala & Korzeniowska, 2023).

Managing quality considers the entire characteristics/features of a given agrifood product, which would determine its ability to satisfy the stated/implied consumer needs. This is what Early (1995) understood when providing the guide to quality management systems for the food industry.

In addition to knowing what quality is, the information about its conformance and design is equally important. Moreover, it is very important that the organization (of quality)is patterned in such a way that it incorporates quality assurance and management strategies. If quality and its management were to work, there is need for moral values to be developed and maintained, which is crucial to the agro-food product industry (Vasconcellos, 2004). Through quality safety standards, agrifood processors become obliged to ensure that (agifood) products meet the required quality safety standards. Good practices have a common objective if carried out effectively and efficiently, which is, to compulsorily ensure the high quality level of agrfood product hygiene and consumer safety (Okpala and Korzeniowska, 2023).

Narrowing down to meat products, the global production was found to be about 60.57 million metric tonnes as of 2020, compared to about 67 million metric tonnes as of 2013 (McGlone, 2013; Cook, 2022; FAO, accessed September 2022). Within the European Union (EU), Poland occupies an important position with respect to the meat industry, whether it is beef, chicken/poultry, as well as pork. For example, Poland in 2021 obtained a total national cattle population of 6.4 million by the head, which placed this country as the sixth (EU) beef producer (Nieuwsbericht, 2022). Additionally, chicken meat in Poland thrives industrially through poultry production, which as of 2021 had amounted to an excess of 2.9 million metric tons (Sas, 2022; Adamski, Kuzniacka, and Milczewska, 2017). Pork in Poland maintains a strong position in meat consumption, having recorded 21.8 million slaughtered pigs in 2016, which was largely driven by supply chain elements of procurement, processing, and distribution (Eurostat, 2017; Cook, 2022; Szymańska, 2015). Meat production would corroborate with the decreasing trend in all domestic animal species as animal farmers confront their self-consumption needs, alongside the limited market demands (Petroman et al., 2013). Besides, meat/meat products remain a positive resource of bioactive compounds for human health/wellbeing. More so, the growing consumer health awareness alongside the intensifying global competition by meat producers cumulatively pressures the need for healthier products, especially targeting preservation strategies (Pogorzelska-Nowicka et al., 2018).

c) Towards achieving optimization of meat products using marination preservation prospects

Herbs and plants possess various beneficial bioactive components amply fortified with nutraceuticals, minerals, vitamins, etc (Okpala, 2019; Awuchi & Okpala, 2022). When applied through the marination process, herbs and plants can serve useful purposes. More so, for the muscle tissue of the desired meat sample to assimilate it, herbs and plants would have to be subject to marination process duration and technique(s) (Siroli et al., 2020; Okpala et al., 2022). Figure 1 shows the principle that guides the marination process in meat products particularly when combined with heat treatment. Promisingly, marinades would be diffused through the meat surface, which facilitates the osmotic penetration of flavor and color. The application of heat would increase the meat tenderness, which eventually influences both flavor and color as marinade is retained (Yusop, O'Sullivan, & Kerry, 2011).

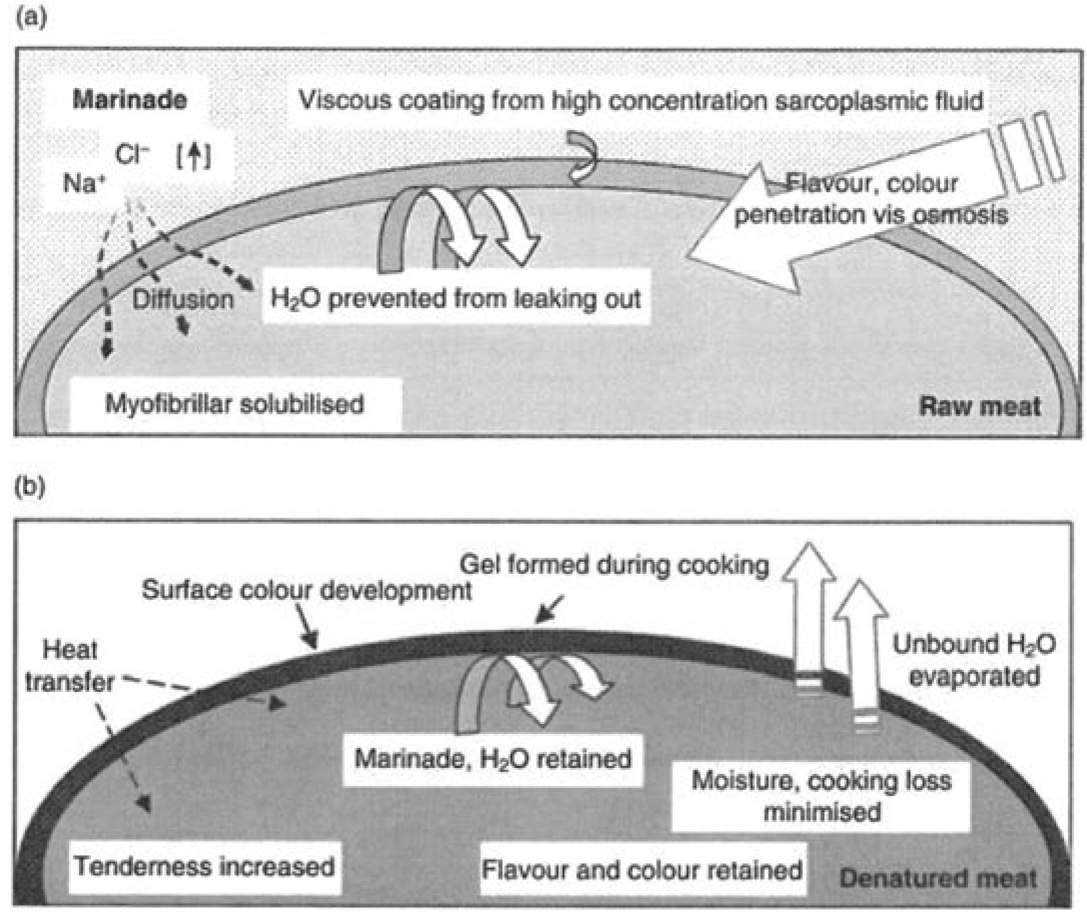

Figure 1: The principle that guides the marination process in meat products particularly when combined with heat treatment (Source: Yusop, O'Sullivan, & Kerry, 2011; Permission given to use from Elsevier Science)

The enhancement/optimization processes of (food)product remains very relative, which makes its implementation in the food industry to certainly vary. According to Erdogdu (2008), the crux of optimization largely targets to achieve the best choice from a given array of alternatives. Previous literature review of Banga et al. (2003) showed that any given optimization procedure would imply changing certain conditions, which would allow for one or more forms of profit maximization, and at the same time, enable the meeting of a given set of constraints. Therefore, to achieve the enhancement of agrifood product requires overcoming production barriers. More so, there is the need for the required knowledge that enables the access to human resources/technical managerial manpower (Prada, 2001; Biegler, Cervantes,& Wächter, 2002). T enhance meat products, the use of marination processes combined with thermal preservation prospects could be alternatives that allow for product development strategies. The application of thermal processes should consider both individual and collective merits in order to satisfy the preservation needs when applied to marinated meat products. The use of natural preservatives specifically involving marinades should enhance the quality attributes of meat products appears to be of increasing interest (Cheok et al., 2011; Istrati et al., 2015; Sokołowicz et al., 2021).

Global meat industry continually strive to maximize product development strategies. In Europe for example, such product development strategies would rely on how as well as what the various stakeholders of the supply chain are able to optimize. Besides, the preservation strategies are steadily fortifying the meat processing techniques. This would underscore the rationale why, according to Vandendriessche (2008), the meat processing/preservation technology involves not only categories I and II (heat treatment), but also categories III and IV (shelf stability) that cumulatively help to either reduce the water activity (drying, salting), as well as both pH and water activity (fermented products). This would further buttress the justification why learning how quality is managed in agro-food technological processes should be prioritized especially from people to products (Okpala, Korzeniowska, and Guiné, 2022a), which is very applicable to the meat industry. Avenues to improve the quality of meat products first require the identification of the needed parameters of interest within the (meat) technological process, followed by their quantification in order to understand how a newly formulated product is realized. Through this, the importance of quality management would be relatable to the agro-food technological process, given the anticipated impact of the enhancement processes (Okpala, Korzeniowska, and Guiné, 2022a; Okpala et al., *accepted for publication*). Nonetheless, there are some prospects where the development of hurdle technology could work alongside a number of either conventional heat processing techniques and/or novel thermal processes so as to particularly combine and be applied to marinated meat products (Okpala et al., *accepted for publication*).

2. Research hypothesis/ problem statement

Giving the increasing living standard across Europe, there has been an emergence to focus on preservation methods that are low-cost, rapid and convenient for consumers. In Poland, the meat industry is widely known to increasingly thrive, especially cattle, pig and poultry sectors (Szymanska, 2017). More so, there appears to be some specific meat products that are increasingly gaining strong attention across communities in Poland, namely beef entrecôte, chicken breast, as well as pork neck (Okpala & Korzeniowska, *personal communication*). Specific to this context, the marination practices would occupy a very important space. More so, given the increasing population diversity, marination variants would continue to evolve across local communities, and their scientific documentation is very scant especially in Poland. In addition, the household electric built-in oven, equipped with a grill, has specifically been hypothesized as a convenient kitchen appliance with promising thermal efficiency, and temperature uniformity (Ma, 2021; Slavova, 2021). For emphasis, a typical oven model, as demonstrated by Ma (2021), is shown in Figure 2. Indeed, grilling using household electric oven appears well positioned to assure meat safety and sensory (culinary) attractiveness. However, as published experimental works as well as synthesized literature that individually involves animal meat products (Farag et al., 2015; Zhao et al., 2020), plant-based marination (Kyriakopoulou, Keppler & van der Goot, 2021; Rathod et al., 2021), as well as thermal processes (applicable to meat products) (Thippareddi & Sanchez, 2006; Bhat et al., 2021) continues to grow, there is need to supplement existing information.

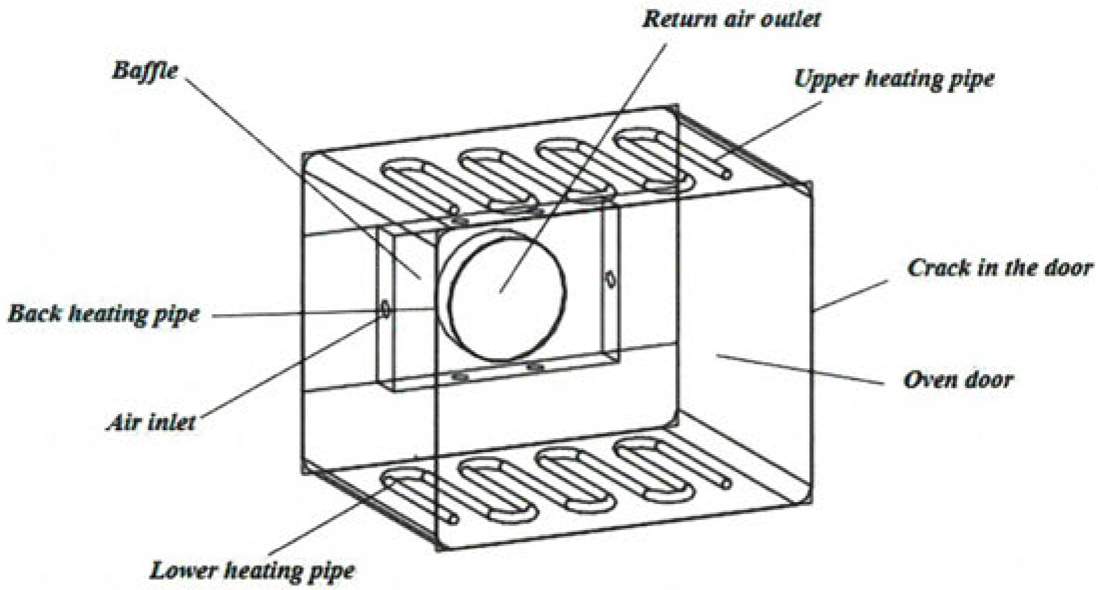

Figure 2: A typical oven model (Source: Ma, 2021; Open access with Creative Commons Attribution 3.0 license)

The continuous improvement of quality safety management systems are essential for proper food processing and handling. Food product development processes should be aimed to motivate consumers (Okpala, Korzeniowska and Guiné, 2022b). Development of a new agrifood product warrants that the quality has to be right with holistic (quality) analysis /evaluation considerations (Okpala, 2021). Understanding how product optimization takes place within the meat industry's process/supply chain is crucial, particularly from stakeholder and product development standpoints. Given that herbs/spices would capably serve as natural preservatives (Awuchi & Okpala, 2022), there are also benefits of thermal processing to meat products (Thippareddi & Sanchez, 2006). That is why how marinated oven grilled meat technology can be improved, and how it relates to quality management in the agro-food sector, is relevant. The identification of plausible marination alternatives would bring about the promise of food preservation strategies. Okpala (2017) opined that formulating the appropriate research questions would help in defining, collecting and reporting of (scientific) information. Up until now, there was paucity of relevant published information specific to different marinated oven-grilled meat products specific to beef entrecôte, chicken breast, and pork neck meat products. Improving marination process should assure superior antioxidative properties and sensory attractiveness of thermally treated meat products. Therefore, by applying selected spices/plant materials, the marination processes should positively affect the raw meat's physicochemical properties, alongside promising shelf durability.

Considering that the personnel's knowledge of quality and its utilization is a key aspect of meat stakeholders supply chain, the schematic flow of quality knowledge and how it is transferred through the various major stages of typical food supply chain is shown in Figure 3, from the production to the consumer stages, all of which are applicable to the meat industry. At each level, from producer to consumer stages and regardless of country, there appears to be an inevitable interaction shown within each stage private sector, as well as government-led personnel that makes effort to assure the sustenance of (meat) quality standards (Ben-Daya et al., 2020). Responsible personnel set out *as per* regulatory framework to ensure quality assurance in the agrifood industry varies from country to country. Within each stage of meat supply chain, for instance, the knowledge of quality that equips each personnel within the industry would be rather challenging to specifically ascertain. This would largely connect with how producers of agrifood products relate with specialization levels of knowledge, methods, skills and technology employed in production (Johnson-Hall & Hall, 2022). To deduce the knowledge of quality of personnel within the meat industry/sector is crucial. For quality to thrive from the very lowest to the highest cadre, all personnel should have the required delivery capacity. Elevating the knowledge base of quality processes for stakeholders within the meat industry supply chain is crucial.

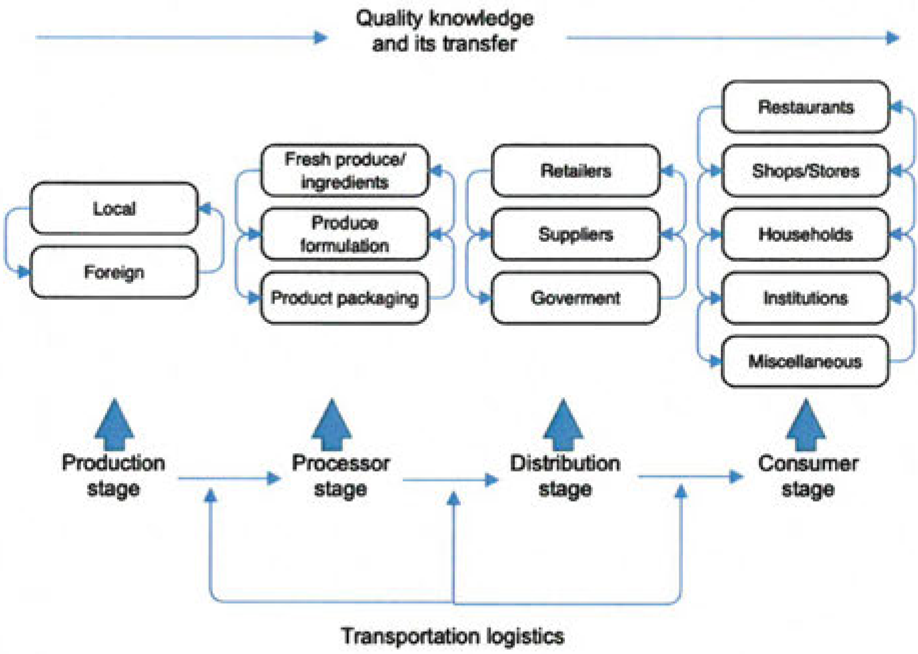

Figure 3: The schematic flow of quality knowledge and its transfer through the various major stages of typical food supply chain, from production to consumer, applicable to the meat industry.

3. Overall aim of the study

-Aim of study

The aim of this current work was focused on the enhancement of marinated oven grilled meat processing in relation to the relevance of quality management in the agrifood sector.

-Specific objectives

a) To review relevant literature, from how quality of animal meat products are enhanced by combining plant-based marinations and thermal processes, to what makes quality management relevant in the agrifood sector;
b) To conduct experimental studies, in order to evaluate: i) the effect of various marination receipts on the culinary quality of different meat types including chicken breast, pork neck and beef entrecôte; ii) the effect of grilling process on the physicochemical properties, antioxidant power and sensorial acceptability.
c) To conduct field studies, which surveyed supply chain stakeholders associated with the meat industry, specifically butchers as well as food retail managers/supervisors, and relate with their knowledge of quality and its utilization.

4. Research methodology

a) Steps followed to conduct the review of relevant literature

Figure 4 shows the schematic overview of literature strategy, which revealed the major stages, from the identification of research databases, to screening of published articles (e.g., literature reviews and experimental types). Other important highlights worth mentioning include, brainstorming of research questions, search strategy, identification as well as formulation of key words employed in searching the various research databases like Scopus, ScienceDirect, Google Scholar, PubMed, as well as Web of Knowledge. It is important to mention that the screening of published articles had to consider, among others, the accessibility/availability of full text, sufficiency/insufficiency of information, relevancy of topic, etc. At all times, efforts were made to ensure the constructive and unbiased approach to conduct the review of relevant literature. Efforts were also made to ensure the relevancy of articles been utilized. To strengthen the scientific discourse of the synthesized information, both tables and figures were developed, and in few instances, adopted. The content areas of the literature reviews were adequately introduced, with various sections. The literature review also identified some research gaps where future experiment/survey works, as well as future literature synthesis would help to fill.

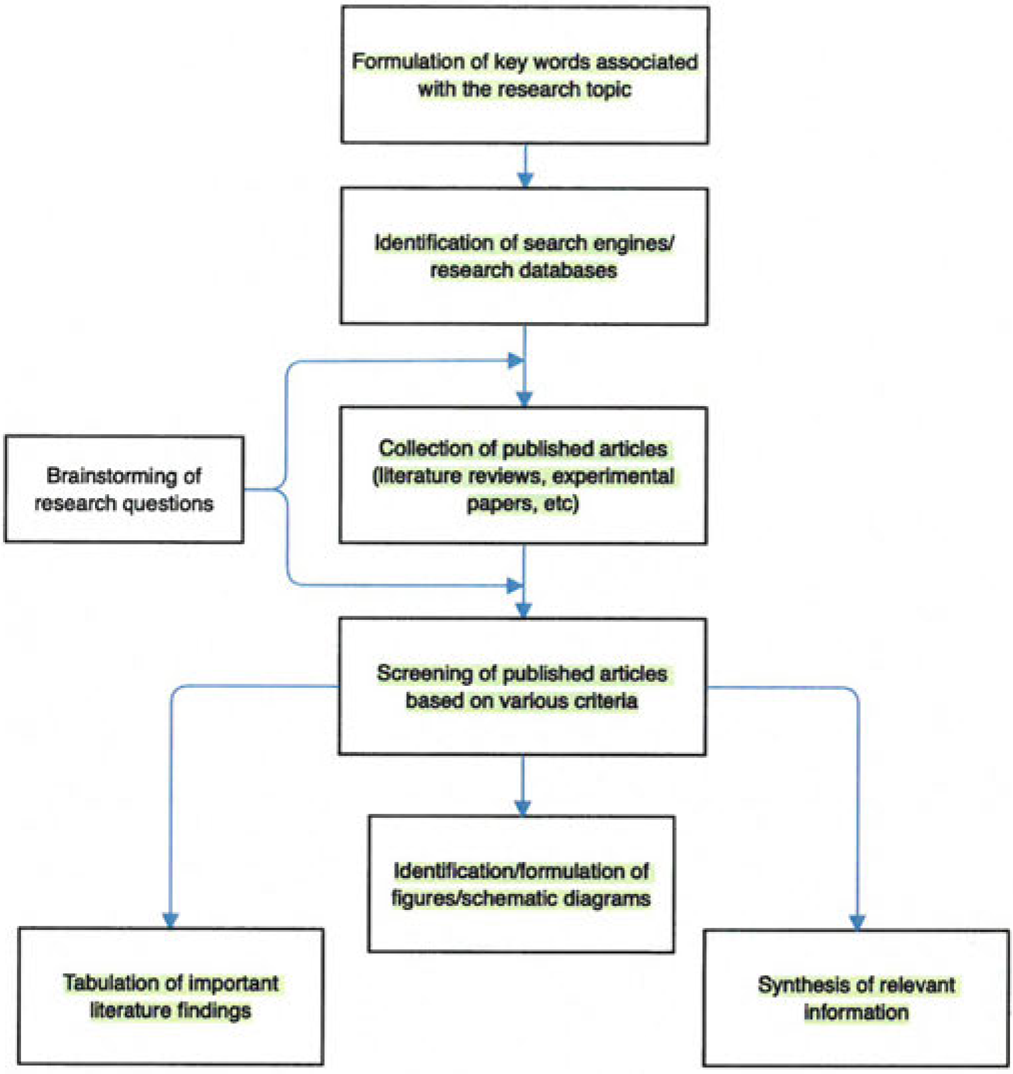

Figure 4: Schematic overview of literature strategy, showing major stages that were followed, how the research databases were identified, screening of the most important articles (literature review as well as data-driven/experimental)

b) Steps followed to conduct the experimental studies involving the formulation of different meat products, and the evaluation of quality attributes

Figure 5 shows the schematic overview of the experimental process, from the assembly of meat products from reputable sources, through the marination process and oven-grill activity, subsequently to the various analytical determinations. Three meat products have been investigated, namely chicken breast, pork neck and beef entrecôte. The different marination variants that were applied specifically involved the constituent 0.5, 1, and 1.5% quantities of cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS), which had either African spice (AS) or industrial marinade/pickle(IM) subsequently incorporated. The oven grill facility was set at a constant cooking time and temperature of 5 min, and 180 degrees Celcius, respectively. The quality attributes were evaluated, namely: (a) Chemical aspects that involved the determinations of antioxidants (2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), pH, as well as thiobarbituric acid reactive substance (TBARS); (b) Physical aspects that involved the determinations of cooking weight loss, L*a*b* color, as well as textural cutting force; and (c) Organoleptic aspects that involved the determinations of sensory (flavour, appearance, tenderness, taste) and texture(hardness, chewiness, gumminess, graininess, and greasiness) components. In all the experimental processes, the independently generated data from different samples were submitted to analysis of variance (ANOVA). Statistical significance was set at $p<0.05$ (95% confidence level).

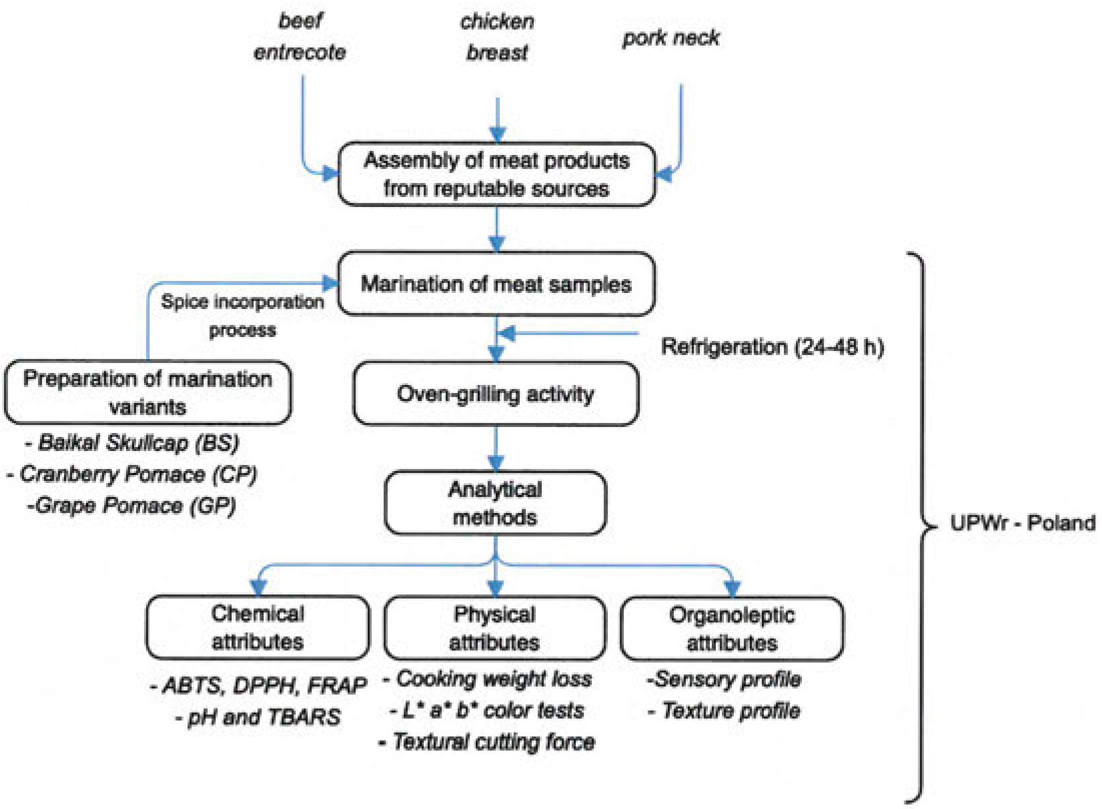

Figure 5: Schematic overview of the experimental process, from the assembly of meat products from reputable sources, through the marination process and oven-grill activity, subsequently to the various analytical determinations.

c) Steps followed to conduct the field surveys involving meat industry and associated stakeholders:

Figure 6 shows the schematic overview of procedures used for the conducted surveys, showing major stages, from identification of the study area/target population, through research logistics and planning, up to data collection, and discussion of results. Indeed, the conducted surveys were deemed necessary given some of the gaps that emanated from the literature synthesis. Specifically, the conducted surveys explored two locations, Nsukka - Nigeria , as well as Wroclaw - Poland. The knowledge and perception of butchers to good hygiene and storage practices in slaughterhouse was performed at Nsukka-Nigeria, whereas how good practices contributed to cleaner production in food retail sector was conducted at Wroclaw-Poland. Each of the of the emergent papers had their schematic flow depict the overview of each conducted survey, which provided snapshots of the respective research methodology. Informed consent was taken from all survey participants prior to their voluntary participation. Study areas, target population, development of research instrument, and other aspects of the survey methodology were appropriately presented. Statistical analyses were included in the survey methodology. Figures and tables were developed to strengthen the discourse.

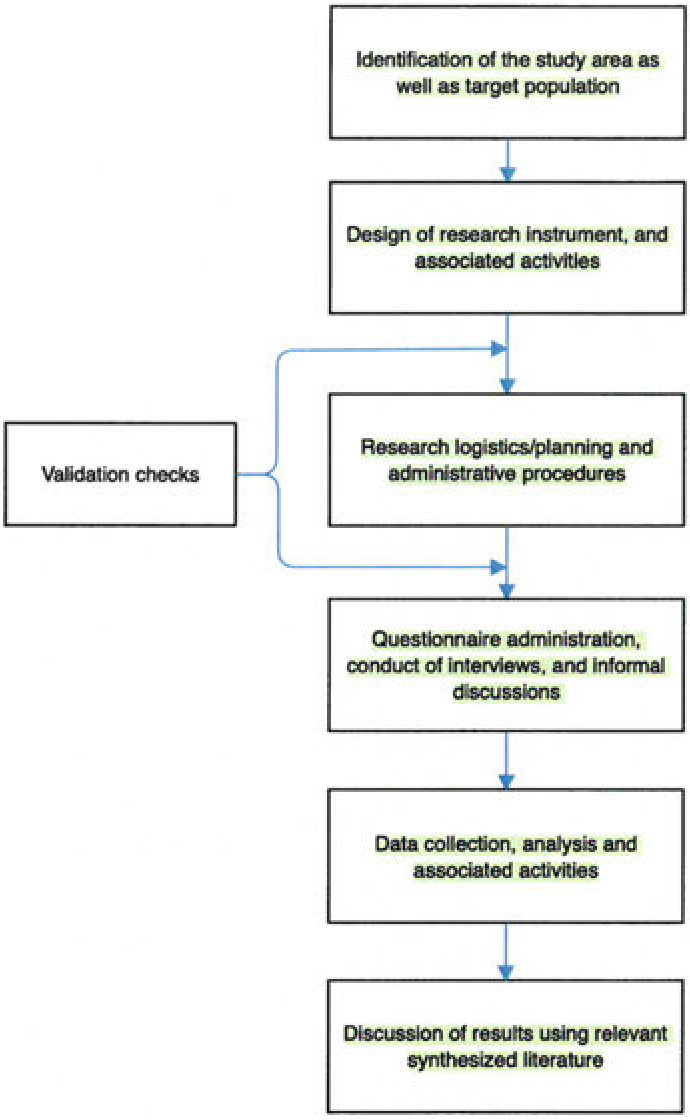

Figure 6: Schematic overview of procedures used for the conducted surveys, showing major stages, from identification of the study area/target population, through research logistics and planning, up to data collection, and discussion of results.

5. Reflections on published works

Objective 1): Review relevant literature, from how quality of animal meat products are enhanced by combining plant-based marinations and thermal processes, to what makes quality management relevant in the agrifood sector

Paper 1: Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (*Accepted for publication*). Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. *Food Sci. Technol. (Campinas).*

Reflections: Various aspects of quality framework that associates with the agrifood product industry, from its basics/fundamentals to the complexities have been considered (Okpala & Korzeniowska, 2020 and 2023). However, to associate with low-cost food preservation/processes approaches such as the use of marinades/marination was deemed pertinent given how this phenomenon commonly relates to consumers. Natural preservatives like those that involve marinades, widely applied to meat products, largely aim to enhance the various quality attributes. Besides that throughout the globe, the production of bovine, porcine, ovine, and caprine animals, including poultry vary, there persists the well-known challenge of meeting the demands/needs of the ever increasing (global) population. Another global issue is the growing awareness regards consumer health, which occurs alongside meat producers being confronted with intensifying competition to deliver healthier products, and this definitely includes preservation strategies. However, as published experimental works as well as synthesised literature individually involving animal meat products, plant-based marination, and thermal processes continues to grow, there is the need to supplement existing information.

Therefore, how quality of animal meat products has been enhanced through plant-based marinations and thermal processes was discussed. Plant-based marination, its preparation and applications, major thermal processes applied to marinated meat products as well as quality implications were deliberated. The major preparation steps to make a marinade are shown in Figure 7, from assembly/collection of herb/spice, through the extraction process, to the refrigerated storage that helps to maintain the freshness. Indeed, the efficacy of plant-based marination, given its applicability to various meat products, appears dependent on factors such as: (a) the adherence to the standard procedures; (b) the incorporation process to the meat product; (c) the marination time; and (d) the constituent mix that makes up the marinade. Obviously, if the marinating methods/process are not adequately implemented, the result would bring about non-desirable quality marinated meat products. Thus, good practices that occupy the fundamentals of food safety knowledge (Okpala & Korzeniowska, 2023) are required to facilitate the process as well as progress of marination technology. If thermal processes, for instance, grilling, were to contribute to enhancing the quality of marinated meat product (Ježek et al., 2020; Thippareddi & Sanchez 2006; Tkacz & Modzelewska-Kapituła, 2022), it has to be applied via good practices in order to achieve high quality level. Therefore, promising quality attributes via thermally processed marinated meat products could be assured to help supplement product development strategies for small-medium meat product enterprises.

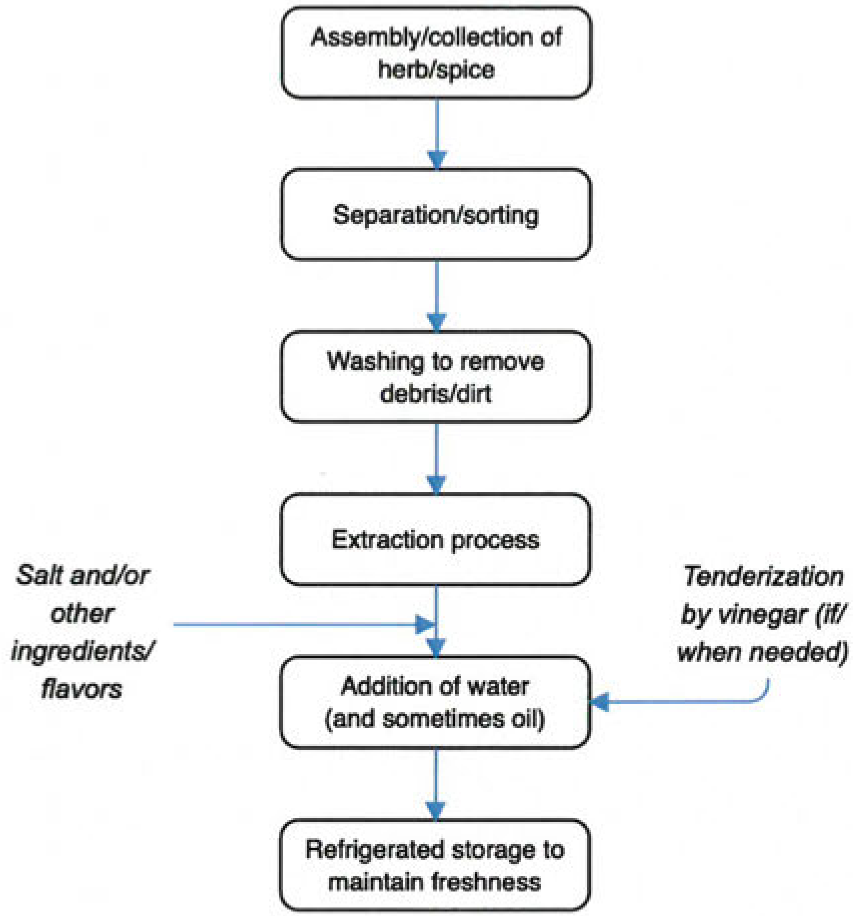

Figure 7: Major preparation steps of making a marinade from assembly/collection of herb/spice, through extraction process, to refrigerated storage that helps to maintain the freshness (Source: Okpala et al., *accepted for publication*; Open access with Creative Commons Attribution 3.0 license)

Paper 2: Okpala, C. O. R., & Korzeniowska, M. (2020). Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. *Front. Nutr.* 7, 578941.

Reflections: Understanding the fundamentals of quality as it relates to any consumer is very important. This is especially true when a consumer enters a food shop to buy any given (food) product. Indeed, quality attributes in agrifood products can be somewhat difficult to identify and observe. The quality of the same agrifood product in two different market shelves would, most likely not be exactly the same when compared to each other, even if both belong to the same batch. Each food product has a specific quality attribute, even within a batch of one product. The basics/fundamentals underlying such peculiarities/specificities can be found either in concept, content, and context perspectives of quality. Prior to this specific paper, no published work had looked at these three aspects together, that is, concept, content, and context perspectives of quality of agrifood products, particularly on how it contributes to the decision-making to purchase an agrifood product. That is why it became needful to look at concept, content, and context perspectives of quality of agrifood products, specifically discussing some reflections on some consumer decision-making purchase scenarios. Indeed, "concept," "content," and "context" perspectives were independently found to project very important meanings to the quality of agrifood products. In the choice/decision-making of purchasing agrifood products, a thin line could likely separate these concept, content, and context perspectives of quality. Figure 8 shows the diagrammatic image of concept, content and context perspectives' interaction of quality found within a given agrifood product, where 'X' represents the interaction between the three. As solely depending on either concept, content, or context perspectives of quality would not suffice, when an interaction between any two, that is, either concept, content, or context perspectives of quality, the consumer is better positioned with improved information about the (given/specific) agrifood product. Obviously, the ideal would be when there is interaction between the three, to inform the consumer with best decision of purchase.

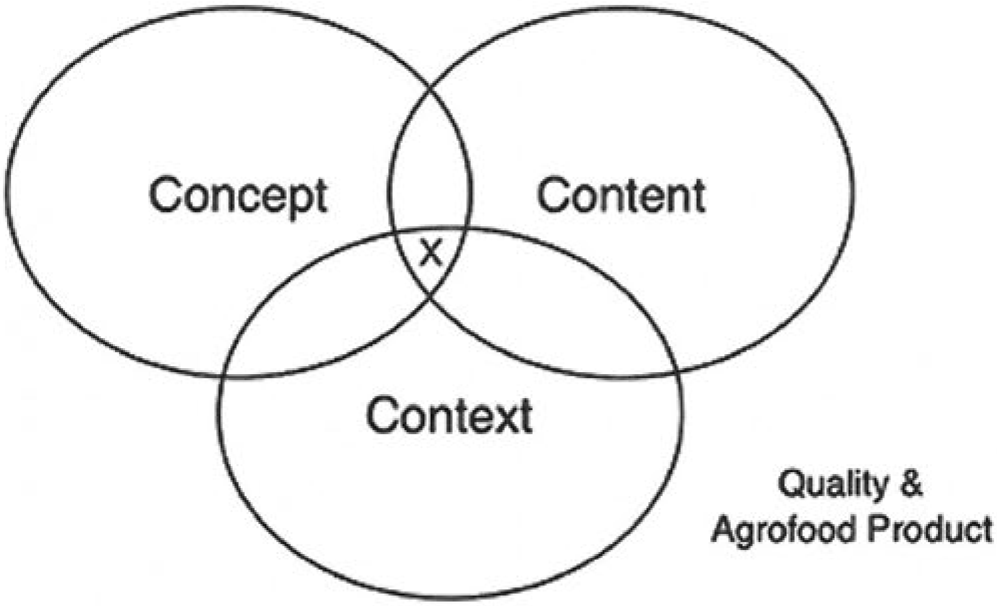

Figure 8: Diagrammatic image of concept, content and context perspectives' interaction of quality found within a given agrofood product, where 'X' represents the interaction between the three (Source: Okpala & Korzeniowska, 2020; Open access with Creative Commons Attribution 3.0 license)

Paper 3: Okpala, C. O. R., & Korzeniowska, M. (2023). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. *Food Rev. Int.* 39(4), 1879-1952.

Reflections: Beyond and deeper into concept, content and context of quality, consumers, stakeholders, as well as agrifood production/technology processes are among key players that occupy the food supply chain. For quality to thrive, there is need for continuous improvement especially starting from the fundamentals, and that is where the implementation of good practices, and where applicable, hazard analysis and critical control points (HACCP) remains very crucial. Indeed, food hygiene, food quality, and food safety must work together, none can do without the other, for the success of agro-food product industry around the globe. That is why, in order to improve the agro-food product quality in a larger scale, the quality management (QM) would have to depend on quality assurance (QA), control, improvement, as well as planning. This literature review was conducted to strengthen our understanding on the assurance of food hygiene quality safety standards and their associated processes. Firstly, in order to understand the relevance of QM in the (above-mentioned) processes, this work discussed some critical elements such as ethical considerations associated with quality, safety standards associated with food quality, the fundamentals as well as implementation of HACCP, control systems associated with QA, as well as other associated quality standards/ supplementary essentials of agro-food industry.

Figure 9 shows the various concepts that make up the relevance of quality management in the agrifood industry, from HACCP, food safety knowledge/standards, good practices, their types and implementation, quality assurance/control, food inspection process/laws, to risk assessment. For instance, the level of quality assurance and what determines its functionality within the food industry would vary from country to country. In Nigeria, for example, there is the National Agency for Food and Drug Administration and Control (NAFDAC) established under the Decree No. 15 of 1993, and as a parastatal of the Federal Ministry of Health, inspects the implementation of good practices (NAFDAC, 2023). Another example is in Poland, where the Act dated October 30, 2003 for food health conditions (Dz. U. 208, position 2020) obligates HACCP system in all food production/processing plants regardless of size (HACCP, 2023). Indeed, the combination of HACCP and QA control points (QACP) would like result to improved food hygiene to enhance and sustain both product/production quality, and safety levels. Notably, therefore, it is not sufficient to establish the QM system within any given agrifood enterprise. What matters most is how to maintain as well as sustain the QM system. This literature review also deliberated upon some of the challenges encountered during both auditing as well as implementation processes involved in the food safety management systems. The literature review ended by providing some directions for future studies, particularly involving food hygiene quality safety, QA, as well as QM.

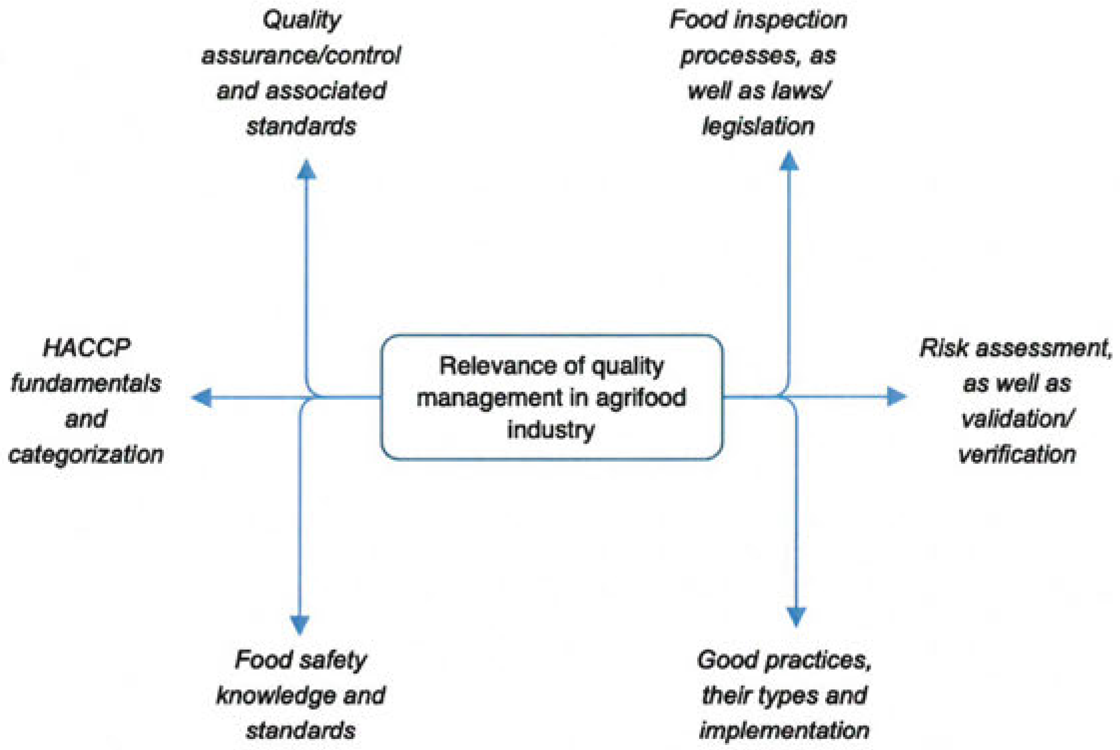

Figure 9: Various concepts that make up the relevance of quality management in the agrofood industry, from HACCP, food safety knowledge/standards, good practices, their types and implementation, quality assurance/control, food inspection process/laws, to risk assessment.

Objective 2) Experimental studies, in order to evaluate: i) the effect of various marination receipts on the culinary quality of different meat types including chicken breast, pork neck and beef entrecôte; and ii) the effect of grilling process on the physicochemical properties, antioxidant power and sensorial acceptability.

Paper 4: Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. *Foods* 11(24), 3951.

Reflections: Thus far in this thesis, some depth of quality associated with the agrifood industry supply chain has been provided, especially with respect to concept, as well as context (Okpala & Korzeniowska, 2023). It should be noted that, quality has to be assured within the supply chain stages of the meat industry, even from the point of slaughter of a given animal, as posited by Okpala, Nwobi and Korzeniowska (2021a and b). When a new meat product is formulated, for instance after marination combined with thermal processing like oven-grill, to establish the quality attributes is crucial particularly at the point of production, prior to short-to-long term storage considerations. That is why at this specific study, the antioxidant, organoleptic, and physicochemical changes in different marinated oven-grilled chicken breast meat were investigated. Specifically, the chicken breast meat samples were procured from a local certified poultry farm/retailer that supply the region of Wroclaw, Poland. Experimentally, the determinations of antioxidant aspects involved 1,1-diphenyl-2-pierylhydrazy (DPPH), 2,2′-azinobis (3-ethylbenzothiaziline- 6-sulfonate (ABTS), and ferric reducing antioxidant power (FRAP). The determinations of organoleptic aspects involved sensory and texture attributes. The determinations of physicochemical aspects involved the cooking weight loss, pH, L* a* b* color, textural cutting force, as well as thiobarbituric acid reactive substance (TBARS).

Figure 10 shows the simplistic flow of marinated oven-grill meat technology towards achieving distinct attributes as shown from different (meat) products. Specific to the chicken breast, the antioxidant, organoleptic and physicochemical range values varied, most of which appeared somewhat limited, across the different marinated oven-grilled chicken breast meat samples. More so, the ABTS and FRAP ranges seemingly widened when either AS or IM were incorporated, but much less at DPPH. With concentration increases in CP, GP, and BS, there appeared to persist some fluctuations in cooking weight loss, L* a* b* color, pH, TBARS, and textural cutting force values despite the incorporation of either AS or IM. There were also resemblances that occurred in some organoleptic sensory/texture profiles. Overall, the oven-grilling process at this study showed the capacity to moderate the range values of antioxidant, organoleptic, and physicochemical components in different marinated chicken breast meat samples.

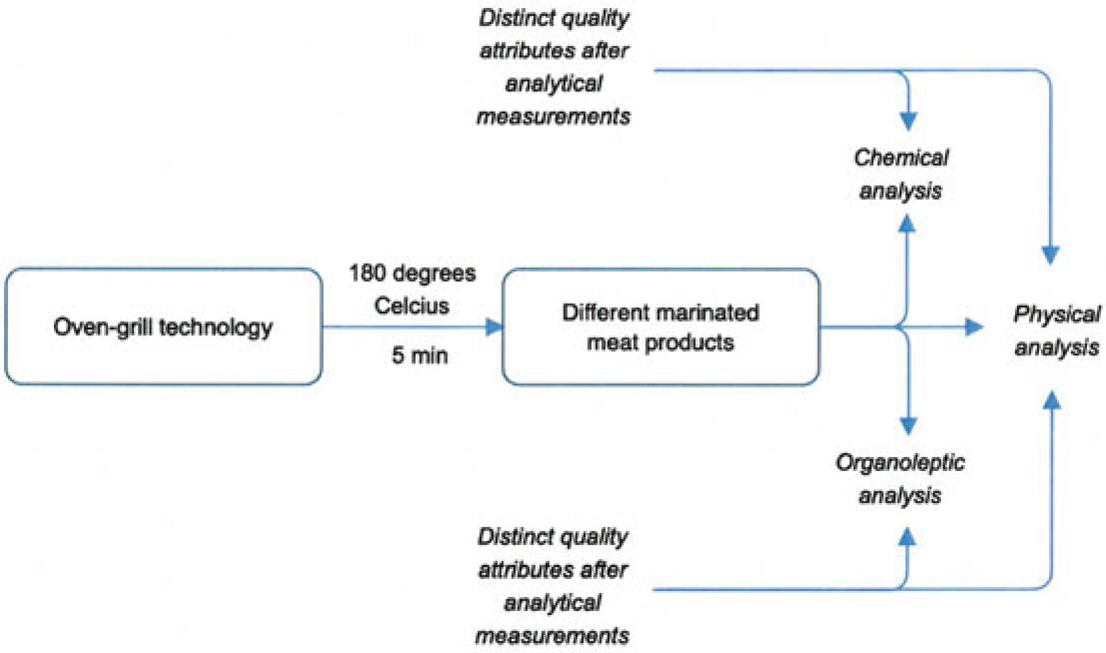

Figure 10: A simplistic flow of marinated oven-grill meat technology towards achieving distinct attributes after analytical measurements as shown from the different tested (meat) products.

Paper 5: Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023a). Quality attributes of different marinated oven-grilled pork neck meat. *Int. J. Food Prop.* 26(1), 453-470.

Reflections: Considering the research outcomes of Okpala et al. (2022), it was deemed very necessary to apply the marination and oven-grill to another meat product. The primary purpose was to see if there would be clear similarities and peculiarities from the data shown in Okpala et al. (2022), and secondarily, to expand the understanding that how quality moved through people through a meat technological process, to emerge as attributes in the new formulated (meat) product. Given that herbs/spices would serve as natural preservatives (Awuchi & Okpala, 2022), and thermal processing would make the animal meat product edible (Thippareddi & Sanchez, 2006), it has been identified that the combination of the two should complement each other (Okpala et al., *accepted for publication*). Additionally, it is believed that there is increase in popularity regards the application of oven grilling to meat products across communities in Poland (Okpala & Korzeniowska, *personal communication*). Prior to this current work, there was paucity of relevant published information regards the different marinated oven-grilled pork neck meat. Therefore, the investigation of quality attributes of different marinated oven-grilled pork neck meat was deemed useful. To ensure the quality authenticity, the pork neck meat has been procured from a porcine farm well known and certified to deliver the Wroclaw region in Poland. The different marination variants were similar to those applied to chicken breast as reported previously(Okpala et al., 2022).

Again, Figure 10 shows the simplistic flow of marinated oven-grill meat technology towards achieving distinct attributes as shown from different (meat) products. Specific to pork neck meat samples, however, some decreases in ABTS, FRAP, DPPH, and TBARS were found, which took place alongside pH variations by difference that seemed to associate with the concentration increases of either CP, BS, or GP. Quite resembling some previously published data (Okpala et al., 2022), the concentration increases of either CP, BS, or GP appeared seemingly not to always go along with the L*a*b* color trends, even when either AS or IM were incorporated. Indeed, the process by which the muscle tissue is able to assimilate the marinades would depend not only on the duration and technique of the marination, but more so, the meat type (Siroli et al., 2020). Further, the sensory aspects showed a number of resemblances, for instance, a number of fluctuating increases in the textural chewiness, gumminess, and hardness of some samples that seemed more evident when AS got incorporated compared to IM. Overall, this work demonstrated that the moderation of range values of quality attributes in different marinated pork neck meat samples at this study could be achieved when oven-grilled.

Paper 6: Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023b). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. *PeerJ* 11, e15116.

Reflections: After marinating and oven-grilling chicken breast, and pork neck meat, and revealing various quality attributes (Okpala et al., 2022 and 2023a), it was deemed necessary to apply this same experimental procedure to beef entrecôte meat. Understanding the impact that combined action of marination and oven grill processes would have on such meat products as beef entrecôte is crucial from both consumer appeal and product development standpoints. That is why it was important to investigate different marinated oven-grilled beef entrecôte meat by specifically evaluating the resultant physicochemical and organoleptic attributes. To ensure quality, the beef entrecôte meat was procured from a reputable local bovine farm/slaughter at Wroclaw, Poland. The marination variants were similar to those previously applied to chicken breast (Okpala et al., 2022), and pork neck (Okpala et al., 2023a), that is, constituent 0.5, 1, and 1.5% quantities of cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS), which subsequently incorporated either African spice (AS) or industrial marinade/pickle(IM).

For emphasis, Figure 10 shows the simplistic flow of marinated oven-grill meat technology towards achieving distinct attributes as shown from different (meat) products. Specific to beef entrecôte, there were varying range values of ABTS, DPPH, FRAP, cooking weight loss, pH, L*a*b* color, TBARS, textural cutting force, as well as organoleptic sensory and textural profiles. In this reflection, it is now clear that these varying range values of marinated oven-grilled beef entrecôte meat samples, were distinct from those reported of chicken breast, and pork neck, despite the concentration increases of either CP, GP, and or BS not always going along with ABTS, DPPH, and FRAP values, considering the observed fluctuations that showed either decreases or increases. The results also showed that, whilst oven-grilling would either increase or decrease the TBARS values of the different marinated beef entrecôte samples along with some color and textural cutting force trends, the observed pH variations by difference would seem more apparent especially at samples that involved GP, prior to CP, and then BS. To establish a clear link by comparisons of color and cooking weight loss across the studied different marinated oven-grilled beef entrecôte samples appeared challenging at this study. Further, some differences and resemblances were found across the organoleptic attributes specifically from the standpoints of sensory and textural profiles. Overall, this work demonstrated that the oven-grilling with capacity to moderate the range values of both physicochemical and organoleptic aspects of different marinated beef entrecôte meat samples at this study.

Objective 3): Field studies, which surveyed supply chain stakeholders associated with the meat industry, specifically butchers as well as food retail managers/supervisors, and relate with their knowledge of quality and its utilization

Paper 7: Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021). Assessing Nigerian Butchers 'Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods* 10(6), 1165.

Reflections: Literature synthesis thus far showed high quality meat product depends on the knowledge, experience and expertise, which would be impacted by the various stages within the supply chain. In order to demonstrate how quality knowledge can be found in people involved in meat technology process, a case study in a Nigeria cattle slaughterhouse was performed. This involved assessing butchers' knowledge and perception of good hygiene and storage practices. Our literature review demonstrated that in Nigeria for example, good practices provides the backbone and core of food quality and safety. More so, the National Agency for Food and Drug Administration and Control (NAFDAC) guides the inspection and production of (beef) meat and prescribes the good practices pertinent to beef products 'handling, processing, and packaging. The various good practices have collective yet specific roles to assure quality within the meat industry. That is why good hygiene practice (GHP) is known to assure beef product safety and consumer protection, whereas good storage practice (GSP) is known to assure the continuity of hygiene activities within the storage stages. Relevant literature about butchers 'knowledge and perception of good hygiene and storage practices within Nigeria slaughterhouses needed more information. That is why understanding butchers 'knowledge and perception of good hygiene and storage practices is very important, and this has been assessed through a cattle slaughterhouse case analysis. The case study location was Nsukka (Enugu State, Nigeria) that situates an increasingly thriving beef market that serves the ever-growing metropolis. The research instrument was a questionnaire, and the study questions were authenticated using content validation approach. The questionnaire comprised a total of 30 questions, and were administered face-to-face interview. Results showed butchers are male (Freq. = 100%, n = 50) dominated, acquired knowledge informally (Freq. = 88%, n = 44), and strongly ($p < 0.0001$) familiar with good hygiene (Freq. = 96%, n = 48), and storage practices (Freq. = 98%, n = 49). Reflecting on this work, the major responses of butchers 'knowledge and perception of good hygiene and storage practices is shown in Figure 11. Butchers clearly embrace good hygiene and storage practices, and their associated activities, even though they are unable to name foodborne pathogens. They also perceive good hygiene and storage practices very strongly, because they know it would help prevent meat contamination/spoilage, as well as foodborne disease spread. Despite the various correlation specific to perception aspects, the butchers demonstrated they strive to continually improve themselves in their slaughterhouse activities, with the aim to assure beef quality and consumer safety.

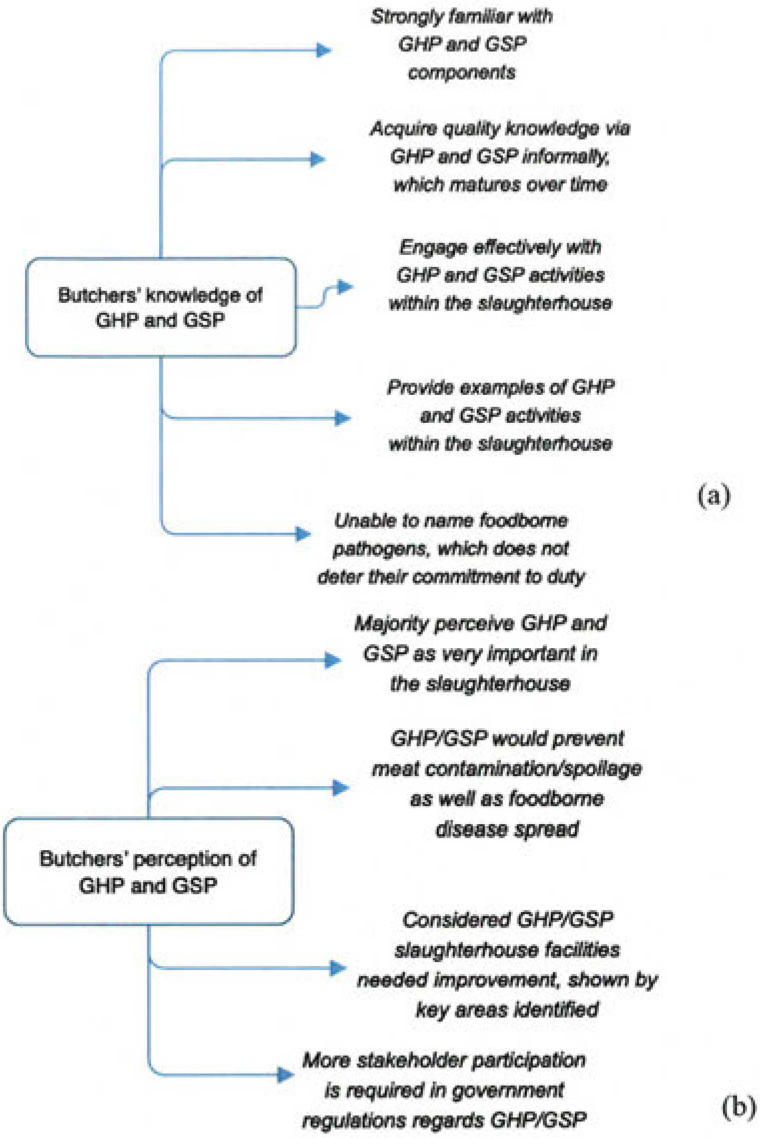

Figure 11: Some essential knowledge (a) and perception (b) of good hygiene (GHP) and storage practices(GSP) by response of butchers

Paper 8: Okpala, C. O. R. (2023). Good Practices contributing to Cleaner Food Production? A Preliminary Survey Analysis involving Wrocław-Poland Food Retail Sector. *Processes* 11(4), 1224.

Reflections: From the literature synthesis conducted by Okpala & Korzeniowska (2023), it was shown that good practices build the fundamentals of food hygiene, quality, as well safety, and all are relevant to the agrifood product industry. To control the food production/processes, there are aspects of good practices that are guided by code of practices, which underscores the effective function of quality assurance activities (Okpala, Nwobi, and Korzeniowska, 2021a and b). With this in mind, good practices, therefore and on one hand, should provide a strong foundation for handling agro-food materials as well as processes. On the other hand, 'cleaner production' entails waste minimization/prevention strategy that helps to increase efficiencies, especially in energy, water, resources, etc. There is a new concept called 'cleaner food production', which appears rather not yet clearly established in existing scientific literature. That is why the question: "Could 'cleaner food production 'either directly or indirectly address some fundamental (food and its related) quality safety challenges/concerns within the agro-food product industry, and at the same time, facilitate the progress of environmental-friendly as well as sustainable processes?" needs to be asked. To help supplement existing information, this preliminary survey analysis sought to find out how good practices contributed towards achieving cleaner food production specific to the context of the 'food retail sector'. In particular, managers/supervisors of the food retail shops/stores in Wrocław-Poland were the target group, which were considered as the case reference. The sampling approached employed was the 'judgement/purposive type'. The questionnaire survey served as the research instrument, which comprised total of 11 questions.

Managers'/supervisors 'responses showed the extent at which their good practices would contribute to achieving cleaner food production in their respective (food) retail sectors/shops. The responses of 'Yes 'dominated across the variables that were tested. Reflecting on this work, Figure 12 can be deduced, which shows the major contributory aspects of good practices by managers/supervisors of retail shops/stores. Managers'/supervisors 'responses considered good practices as compulsory responsibility, which through this knowledge, they are able to elevate the environmental awareness of the consumer/customer who visit their food retail shops/stores. Managers'/supervisors 'responses also showed that good practices facilitated the identification of cleaner production components. Besides the 53 statistically significant correlations, some of which showed perfect linear association, when this current preliminary survey analysis was considered holistically, the author was able to come up with a potential definition of 'cleaner food production' specific to the context of (food) retail sector and service, that is, "*the effective and efficient utilization of good practices to deliver high quality food retail products through environmental-friendly as well as sustainable processes*".

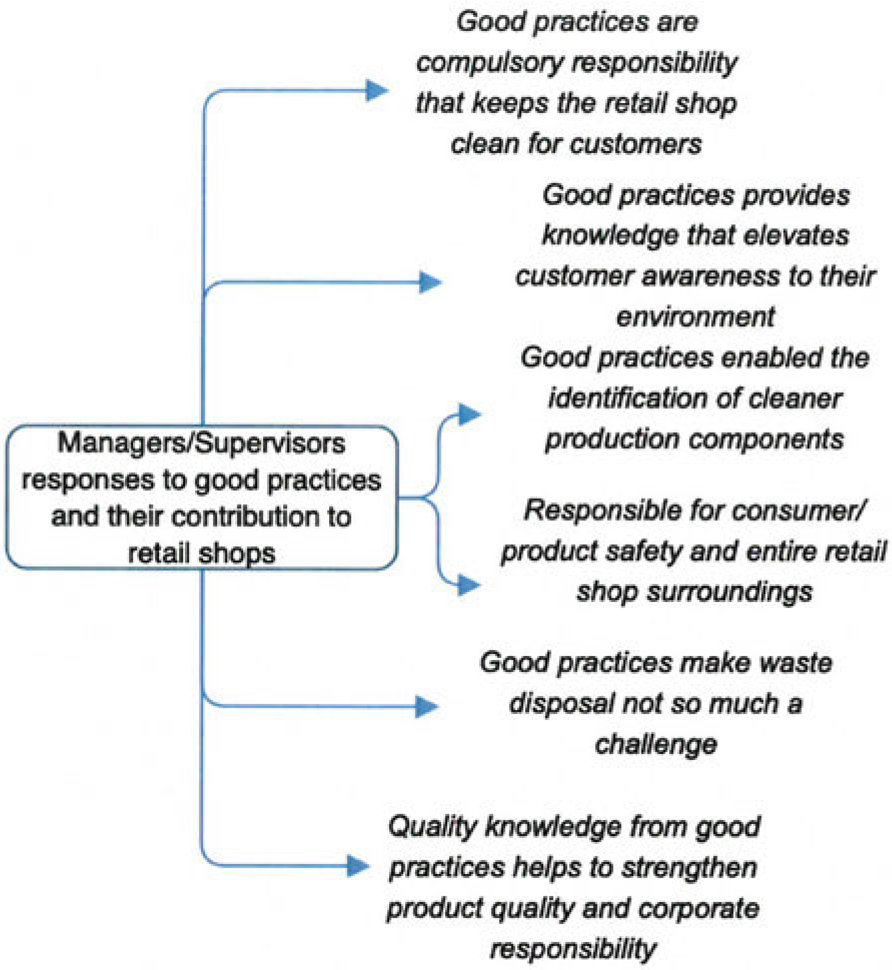

Figure 12: Some essential contributory aspects of good practices by response of managers/supervisors of retail shops/stores

6. Summary and recommendation for future studies

Marinated oven-grill meat processing can be enhanced when applied to different meat products, namely, chicken breast, beef entrecôte, as well as pork neck, given the obtained distinct characteristic ranges/trends. To establish a collective organoleptic trend proved challenging given the statistical fluctuations/resemblances across the different marinated oven-grilled meat products. Marinated oven-grill meat processing promised to moderate the range values of quality attributes of the tested chicken breast, beef entrecote, and pork neck meat products. This current work reiterated the importance of marination practices in meat processing/technology. Considering both conducted field surveys and marinated oven-grilled meat experimentation, there should be relation points of quality assurance/management. Figure 13 shows the various points where quality assurance/ management relate meat stakeholders with marinated oven-grill process processing. Regardless of the types, good practices would continue to occupy the fundamentals of quality assurance/management. Moreover, the meat stakeholders deliver the quality management in agro food industry, which was demonstrated by butchers that embraced good hygiene and storage practices, and food retail managers/supervisors that utilized the good practices to facilitate the identification of cleaner production components, and enhance environmental awareness of consumers/customers. In the context of the food retail sector, a definition of 'cleaner food production 'was proposed.

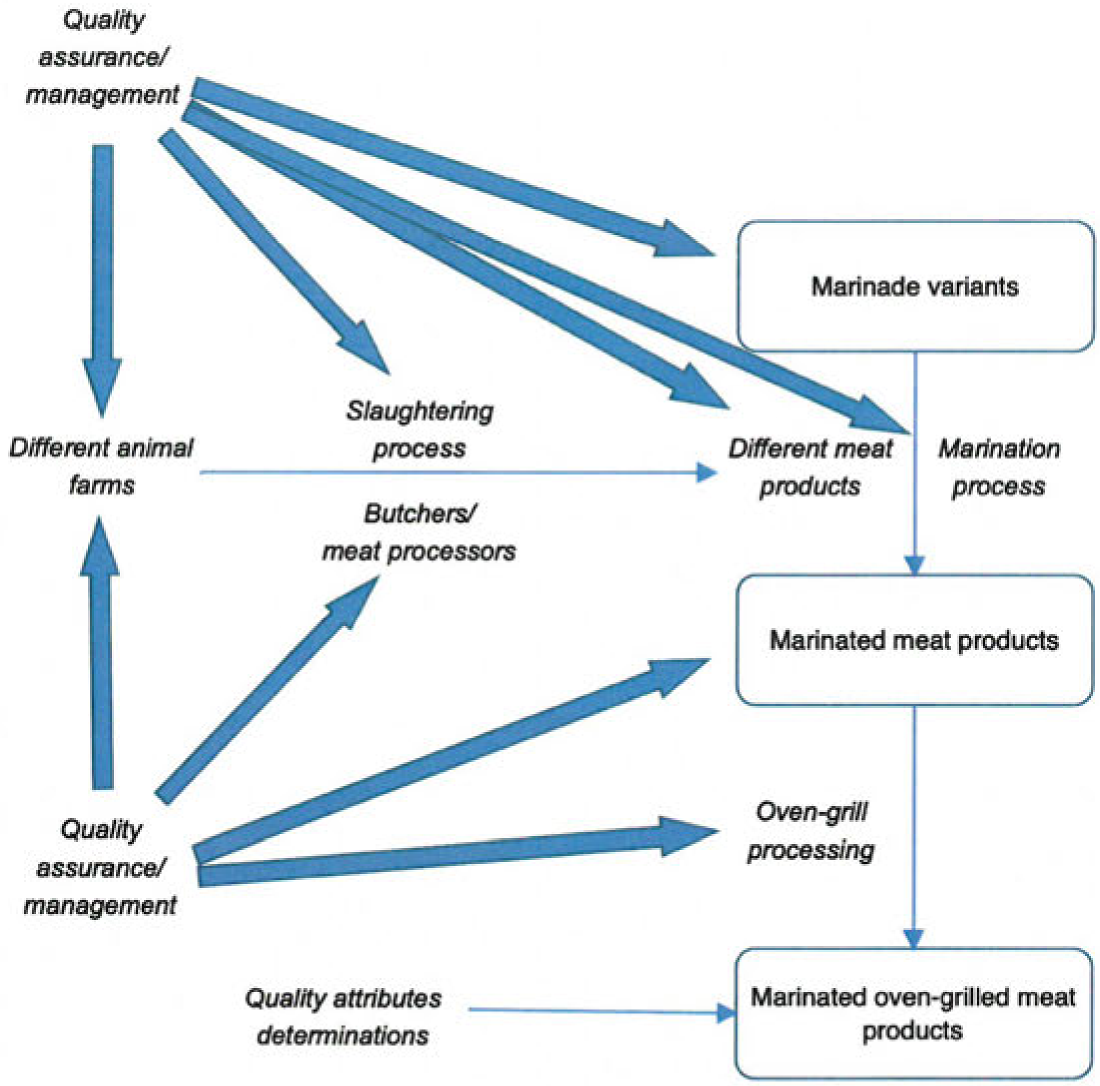

Figure 13: Various points where quality assurance/ management relate meat stakeholders with marinated oven-grill process processing. Regardless of the types, good practices would continue to occupy the crux/fundamentals of quality assurance/management.

Butchers' capacity to embrace GHP/GSP, together with the food retail managers/supervisors to identify with cleaner production components demonstrated their knowledge/continuous improvement of quality safety management systems. The conducted synthesized literature reviews, experimental works and surveys cumulatively provided some recommendations. For the conducted synthesized literature reviews, future works need to examine the influential factors that connect consumer quality perspectives from the standpoints of shelf standards that control agrifood products. For the conducted experimental works, future works need to: (a) deduce the microbiological and preservative efficacy of the oven grill technique by subjecting the marinated meat product samples to different packaging and refrigerated storage conditions; and (b) identify the various bioactive compounds in the marinades, and their underlying molecular mechanisms within the studied oven-grilled (marinated) meat products. For the conducted surveys, future works need to: (a) deduce the frequent usage of cleaning facilities/procedures with respect to years of work experience;(b) identify risk factors for 'poor hygiene' or 'positive factors' for good hygiene as it relates to other explanatory variables; as well as (c) incorporate wider 'food technological 'facets with those stakeholders that occupy the agrifood supply chain in order to enhance the 'cleaner food production 'debate beyond the food retail context.

References

1. Adamski, M., Kuzniacka, J., & Milczewska, N (2017). Preferences of consumers for choosing poultry meat. *Polish J. Nat. Sci.* 32, 261–271.
2. Awuchi, C. G., & Okpala, C. O. R. (2022). Natural nutraceuticals, especially functional foods, their ma-jor bioactive components, formulation, and health benefits for disease prevention-An overview. *J. Food Bioact. 19.*
3. Banga, J. R., Balsa-Canto, E., Moles, C. G., & Alonso, A. A. (2003). Improving food processing using modern optimization methods. *Trends Food Sci. Technol. 14*(4), 131-144.
4. Ben-Daya, M., Hassini, E., Bahroun, Z., & Banimfreg, B. H. (2020). The role of internet of things in food supply chain quality management: A review. *Qual. Manag. J. 28*(1), 17-40.
5. Biegler, L. T., Cervantes, A. M., & Wächter, A. (2002). Advances in simultaneous strategies for dynamic process optimization. *Chem. Eng. Sci. 57*(4), 575-593.
6. Bhat, Z. F., Morton, J. D., Bekhit, A. E. D. A., Kumar, S., & Bhat, H. F. (2021). Thermal processing implications on the digestibility of meat, fish and seafood proteins. *Comp. Rev. Food Sci. Food Saf. 20*(5), 4511-4548.
7. Bojnec, Š., Fertő, I., & Fogarasi, J. (2014). Quality of institutions and the BRIC countries agro-food exports. *China Agric. Econ. Rev.* 6(3), 379-394.
8. Bremner, H.A. (2000). Toward practical definitions of quality for food science. *Crit. Rev. Food Sci. Nutr.* 40, 83–90.
9. Bruntrup, M., Swetman, T., Michalscheck, M., & Asante, F. (2013). Factors of success and failure of large agro-enterprises (produstion, processing and marketing) a pilot study in

Ghana: results of case studies in the fruit, maize, and palm oil sub-sectors. *Afr. J. Food Agri. Nutr. Dev. 13*(5), 29-59.

10. Cheok, C. Y., Chin, N. L., Yusof, Y. A., Mustapa Kamal, S. M., & Sazili, A. Q. (2011). Effect of marinating temperatures on physical changes of traditionally marinated beef satay. *J. Food Process. Preserv. 35*(4), 474-482.
11. Cook, R. (2022). Ranking Of Countries That Produce The Most Pork (USDA), Beef2Live. https://beef2live.com/ story-ranking-countries-produce-pork-usda-508-213044 Accessed 04 September 2022
12. Dequiedt V. (2018). Product Quality in Developing Countries Agrifood Supply Chains: A Survey of Theory. Universite Clermont Auvergne, CNRS, IRD, CERDI, France, pp. 19, November 2018.Available online at: https://ferdi.fr/dl/ df-r5s6cxeybQjy546NQfyLoL7t/papier-de-recherche-product-quality-indeveloping-countries-agrifood-supply.pdf (Accessed September 1, 2020).
13. Erdogdu, F. (2008). *Optimization in Food Engineering*, Boca Raton, CRC Press, pp. 758, ISBN: 9780429148811
14. Eurostat. (2017). Pork production up in the EU. Products Eurostat News, Published 19-09-2017. https://ec. europa.eu/eurostat/web/products-eurostat-news/-/DDN-20170919-1 (Accessed 28 December 2022)
15. Farag, M. R., Alagawany, M., Abd El-Hack, M. E., Tiwari, R., & Dhama, K. (2015). Identification of different animal species in meat and meat products: trends and advances. *Adv. An. Vet. Sci. 3*(6), 334-346.
16. Fałkowski, J., Curzi, D., & Olper, A. (2019). Contracting institutions, agro-food trade and product quality. *J. Agric. Econ.*70(3), 749-770.

17. Gheorghe I. (2012). Analysis of Agro-food Products'Quality. Competitiveness of Agro-Food and Environmental Economy, 229, CAFEE'12 Bucharest Conference, 8-9 November, 2012.

18. Goodman, D (2003). The quality turn and alternative food practices: reflections and agenda. *J. Rural Stud.* 19:1– 7.

19. HACCP (2023). HACCP - Hazard Analysis and Critical Control Point, https://climateloggers.com/en/haccp.html, Accessed 02 May 2023.

20. Hygreeva, D., & Pandey, M. C. (2016). Novel approaches in improving the quality and safety aspects of processed meat products through high pressure processing technology-A review. *Trends Food Sci. Technol. 54*, 175-185.

21. Ilbery B, & Kneafsey M. (2000) Producer constructions of quality in regional speciality food production: a case study from south west England. *J. Rural Stud.* 16:217–230.

22. Istrati, D., Simion Ciuciu, A. M., Vizireanu, C., Ionescu, A., & Carballo, J. (2015). Impact of Spices and Wine-Based Marinades on Tenderness, Fragmentation of Myofibrillar Proteins and Color Stability in Bovine *Biceps Femoris* Muscle. *J. Texture Stud. 46*(6), 455-466. https://doi.org/10.1111/jtxs.12144

23. Ježek, F., Kameník, J., Macharáčková, B., Bogdanovičová, K., & Bednár, J. (2020). Cooking of meat: Effect on texture, cooking loss and microbiological quality—A review. *Acta Vet. Brno* 88, 487–496

24. Johnson-Hall, T. D., & Hall, D. C. (2022). Redefining Quality in Food Supply Chains via the Natural Resource Based View and Convention Theory. *Sustainability 14*(15), 9456.

25. Juran, J. M. (1994). The Upcoming Century of Quality. *Qual. Prog.* 27(8), 29–37.

26. Kennedy, J.; Jackson, V.; Blair, I. S.; McDowell, D. A.; Cowan, C.; and Bolton, D. J. (2005). Food Safety Knowledge of Consumers and the Microbiological and Temperature Status of Their Refrigerators. *J. Food Prot.* 2005, 68(7), 1421–1430.

27. Kohls, R.L., and Uhl, J.M. (2015). Marketing of Agricultural Products, 9th Edition, Pearson India Education, pp. 560, ISBN: 978-9332556966

28. Kyriakopoulou, K., Keppler, J. K., & van der Goot, A. J. (2021). Functionality of ingredients and additives in plant-based meat analogues. *Foods 10*(3), 600.

29. López, X.A., and Martin, B.G. (2006). Tourism and quality agro-food products: an opportunity for the spanish countryside. *Tijdschrift voor economische en sociale geografie* 97:166–177.

30. Ma, Q. (2021). Research on the Key Factors of Improving Thermal Efficiency and Temperature Uniformity of Oven. In *IOP Conference Series: Earth and Environmental Science* (Vol. 631, No. 1, p. 012113). IOP Publishing.

31. McGlone, J. J. (2013). The future of pork production in the world: towards sustainable, welfare-positive systems. *Animals*, *3*(2), 401-415.

32. Medeiros, L. C., Hillers, V. N., Chen, G., Bergmann, V., Kendall, P., & Schroeder, M. (2004) Design and Development of Food Safety Knowledge and Attitude Scales for Consumer Food Safety Education. *J. Am. Diet. Assoc.* 104 (11), 1671–1677.

33. Medeiros, L. C., Hillers, V. N., Kendall, P., & Mason, A (2001). Evaluation of Food Safety Education for consumers. *J. Nutr. Educ.* 33, S27–S34.

34. Mihalache, O. A., Dumitraşcu, L., Nicolau, A. I., & Borda, D. (2021).Food Safety Knowledge, Food Shopping Attitude and Safety Kitchen Practices among Romanian Consumers: A Structural Modelling Approach. *Food Cont.* 120, 107545.

35. NAFDAC (2023). National Agency for Food and Drug Administration and Control (NAFDAC), https://www.nafdac.gov.ng/, Accessed 02 May 2023

36. Nieuwsbericht (2022), The potential for development of Polish beef, published 02-03-2022, https://www.agroberichtenbuitenland.nl/actueel/nieuws/2022/03/02/the-potential-for-development-of-polish-beef, Accessed 26 October 2022

37. Nilsson, J., & Dijk, G. V. (1997). Strategies and structures in the Agro-food industries. Assen, The Netherlands: Van Gorcum & Comp. B.V., pp. 297, ISBN 90 232 3264X

38. Okpala, C. O. R. (2017). Reflecting in the Woods: Can it Help to Enhance the Formulation of (our) Research Questions?. *BioResources* 12(3), 4490-4494.

39. Okpala, C. O. R. (2019). Towards enhancing the detection of adulteration in bioactive food products. *Journal of Food Bioactives* 6, 6-9.

40. Okpala, C.O.R. (2021). Importance of quality evaluation of functional foods and key processes in its new product development. Presentation delivered at the UPWr Food Technology Summer School held 5-9th July 2021, Wrocław University of Environmental and Life Sciences, Wrocław-Poland, DOI: 10.13140/RG.2.2.30210.81605

41. Okpala, C. O. R. (2023). Good Practices contributing to Cleaner Food Production? A Preliminary Survey Analysis involving Wrocław-Poland Food Retail Sector. *Processes* 11(4), 1224.

42. Okpala, C. O. R., & Korzeniowska, M. (2020). Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. *Front. Nutr.* 7, 578941.

43. Okpala, C. O. R., & Korzeniowska, M. (2023). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food

hygiene quality safety standards and its associated processes. *Food Rev. Int.* 39(4), 1879-1952.

44. Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021a). Assessing Nigerian Butchers 'Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods* 10(6), 1165.
45. Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021b). Towards delineating butchers 'knowledge base, challenges encountered, and enhancement prospects of meat inspection processes: A cattle slaughterhouse case analysis. *Meat Technol. 62*(1), 41-56.
46. Okpala, C. O. R., Korzeniowska, M., and Guiné, R. P. F. (2022a). Towards managing quality in agro-food technological processes: From people to products. Poster presented at the 9th Quality and Safety in Food Production Chain Conference, 15-16 September 2022, Wroclaw-Poland.
47. Okpala, C. O. R., Korzeniowska, M., and Guiné, R. P. F. (2022b). Good practices in food product development processes: Some keys to motivating the consumer. Presentation delivered at the International Web Conference on Food Choice & Eating Motivation, 19 - 20 May 2022, organised by Polytechnic Institute of Viseu, Portugal.
48. Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (*Accepted for publication*). Enhancing quality of animal meat products combining plant-based marinations and thermal processes: A treatise. *Food Sci. Technol.* (Campinas).
49. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. *Foods* 11(24), 3951.

50. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023a). Quality attributes of different marinated oven-grilled pork neck meat. *Int. J. Food Prop.* 26(1), 453-470.

51. Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023b). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. *PeerJ* 11, e15116.

52. Petroman, C., Petroman, I., Negruţ, V., Marin, D., Ciolac, R., & Văduva, L. (2013). Frequency of Consumption of Meat and Meat Products in Timis County. *Scientific Papers: Animal Science & Biotechnologies/Lucrari Stiintifice: Zootehnie si Biotehnologii*, *46*(2).

53. Pogorzelska-Nowicka, E., Atanasov, A. G., Horbańczuk, J., & Wierzbicka, A. (2018). Bioactive compounds in functional meat products. *Molecules*, *23*(2), 30

54. Prada, C. D. (2001) Advanced control and supervision in the sugar industry. In First Workshop on Mathematical and Computing Techniques for Agrofood Technologies, CIMNE (UPC), Barcelona, Spain, 26–27 November 2001

55. Rathod, N. B., Kulawik, P., Ozogul, F., Regenstein, J. M., & Ozogul, Y. (2021). Biological activity of plant-based carvacrol and thymol and their impact on human health and food quality. *Trends in Food Sci. Technol. 116*, 733-748.

56. Raspor, P., & Jevšnik, M (2008). Good Nutritional Practice from Producer to Consumer. *Crit. Rev. Food Sci. Nutr.* 48 (3), 276–292.

57. Sas, A (2022). Production of Meat and Meat Products in Poland 2018–2021, by Product Type, Agriculture-Farming, Statistica. 2022. Available online: https://www.statista.com/statistics/1125806/poland-production-of-meat-and-meat-products/ (accessed on 11 October 2022).

58. Siroli, L., Baldi, G., Soglia, F., Bukvicki, D., Patrignani, F., Petracci, M., & Lanciotti, R. (2020). Use of essential oils to increase the safety and the quality of marinated pork loin. *Foods*, *9*(8), 987.

59. Sivam, G.P., 2001. Protection against Helicobacter pylori and other bacterial infections by garlic. *J. Nutr.* 131, 1106S-1108S.

60. Slavova, Y. (2021). Determining the Efficiency of an Electric Oven in the Grill Heating Mode. In *2021 17th Conference on Electrical Machines, Drives and Power Systems (ELMA)* (pp. 1-4). IEEE.

61. Sokołowicz, Z., Augustyńska-Prejsnar, A., Krawczyk, J., Kačániová, M., Kluz, M., Hanus, P., & Topczewska, J. (2021). Technological and Sensory Quality and Microbiological Safety of RIR Chicken Breast Meat Marinated with Fermented Milk Products. *Animals* *11*(11), 3282.

62. Szymańska, E. J. (2015). Functioning of the supply chain of pork in Poland. *J. Agribus. Rural Dev. 37*(3).

63. Szymanska, E. J. (2017). Determinants of profitability of enterprises of meat industry in Poland. *Acta Sci. Pol. Oecon. 16*(3), 83-91

64. Thippareddi, H., & Sanchez, M. (2006). *Thermal processing of meat products*. Thermal Food Processing New Technologies and Quality Issue; Taylor & Francis: New York, NY, USA.

65. Tkacz, K., Tylewicz, U., Pietrzak-Fiećko, R., & Modzelewska-Kapituła, M. (2022). The Effect of Marinating on Fatty Acid Composition of Sous-Vide Semimembranosus Muscle from Holstein-Friesian Bulls. *Foods* 11, 797.

66. Vandendriessche, F. (2008). Meat products in the past, today and in the future. *Meat Sci. 78*(1-2), 104-113.

67. Varzakas, T., a & Tzia, C. (2016). *Handbook of Food Processing, Food Safety, Quality and Manufacturing Processes*. Florida, USA. CRC Press:676. ISBN: 978-1-4987-2178-3

68. Vasconcellos, J A. (2004). *Quality Assurance for the Food Industry: A Practical Approach*. Boca Raton, FL: CRC Press LLC, pp. 448, ISBN: 978-0849319129.

69. Yusop, S. M., O'Sullivan, M. G., & Kerry, J. P. (2011). Marinating and enhancement of the nutritional content of processed meat products. In: *Processed meats, Improving Safety, Nutrition and Quality*, Woodhead Publishing Series in Food Science, Technology and Nutrition, pp. 421-449.

70. Zhao, J., Li, A., Jin, X., & Pan, L. (2020). Technologies in individual animal identification and meat products traceability. *Biotechnol. Biotechnol. Equip. 34*(1), 48-57.

CCC
RightsLink

Home | Help | Email Support | Charles Okpala

Chapter:
17 Marinating and enhancement of the nutritional content of processed meat products
Book: Processed Meats
Author: S.M. Yusop,M.G. O'Sullivan,J.P. Kerry
Publisher: Elsevier
Date: 2011

Order Completed

Thank you for your order.

This Agreement between Charles Okpala ("You") and Elsevier ("Elsevier") consists of your license details and the terms and conditions provided by Elsevier and Copyright Clearance Center.

Your confirmation email will contain your order number for future reference.

License Number	5571281311026
License date	Jun 17, 2023

Printable Details

Licensed Content

Licensed Content Publisher	Elsevier
Licensed Content Publication	Elsevier Books
Licensed Content Title	Processed Meats
Licensed Content Author	S.M. Yusop,M.G. O'Sullivan,J.P. Kerry
Licensed Content Date	Jan 1, 2011
Licensed Content Pages	29

Order Details

Type of Use	reuse in a thesis/dissertation
Portion	figures/tables/illustrations
Number of figures/tables /illustrations	1
Format	both print and electronic
Are you the author of this Elsevier chapter?	No
Will you be translating?	No

About Your Work

Title	The effect of marination process on meat quality in relation to the relevance of quality management in the agrifood sector
Institution name	Wroclaw University of Environmental and Life Sciences
Expected presentation date	Nov 2023

Additional Data

Portions	2

Requestor Location

	Charles Okpala University of Georgia Athens
Requestor Location	ATHENS, GA 30601 United States Attn: Charles O Okpala

Tax Details

Publisher Tax ID	98-0397604

Price

Total	0.00 USD

Total: 0.00 USD

CLOSE WINDOW ORDER MORE

Gmail

Charles Okpala <charlesokpala@gmail.com>

Food Science and Technology - Decision on Manuscript ID CTA-2022-1267.R1

1 message

Adriano Cruz <onbehalfof@manuscriptcentral.com> 6 April 2023 at 07:30
Reply-To: adriano.cruz@ifrj.edu.br
To: charlesokpala@gmail.com

06-Apr-2023

Dear Dr. Okpala:

It is a pleasure to accept your manuscript entitled "Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise" in its current form for publication in the Food Science and Technology. The comments of the reviewer(s) who reviewed your manuscript are included at the foot of this letter.

Thank you for your fine contribution. On behalf of the Editors of the Food Science and Technology, we look forward to your continued contributions to the Journal.

Sincerely,
Dr. Adriano Cruz
Editor-in-Chief, Food Science and Technology
adriano.cruz@ifrj.edu.br

Associate Editor
Comments to the Author:
(There are no comments.)

Entire Scoresheet:

Accepted at: *Food Science and Technology* (Campinas)

Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise

Charles Odilichukwu R. Okpala[1,2]*, Mouandhe Imamou Hassani[3], Małgorzata Korzeniowska[1]* , and Raquel P.F. Guiné[4]

[1]Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wroclaw University of Environmental and Life Sciences,50-630 Wroclaw, Poland, charlesokpala@gmail.com (COROkpala); malgorzata.korzeniowska@upwr.edu.pl (MKorzeniowska)

[2]UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia Athens, GA 30602, United States

[3]Institut National de Recherche pour L'Agriculture, La Pêche et L'Environnement (INRAPE), Moroni BP 1406, Comoros, mouandhe04906@gmail.com(M Imamou Hassani)

[4]CERNAS Research Centre, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal , raquelguine@esav.ipv.pt(RPF Guiné)

***Correspondence:** Charles Odilichukwu R. Okpala (charlesokpala@gmail.com); Małgorzata Korzeniowska(malgorzata.korzeniowska@upwr.edu.pl)

Abstract

Nowadays, natural preservatives specifically involving marinades are being applied to meat products to enhance various quality attributes. The need for food preservation has continually strengthened the processing of meat products. Besides the global production of bovine, porcine, ovine, and caprine animals, including poultry that vary across continents, however, meeting the demands/needs of ever increasing (global) population remains the focus. The growing consumer health awareness alongside intensifying global competition by meat producers cumulatively strengthens the call for healthier products, including preservation strategies. However, as published experimental/synthesised literature involving animal meat products, plant-based marination, and thermal processes continues to grow, there is need to supplement existing information. Therefore, this treatise aims to discuss how quality of animal meat products has been enhanced through plant-based marinations and thermal processes, drawing from a) plant-based marination: some key examples, and usefulness; b) marination/marinades: briefs on preparation and applications; c) major thermal processes applied to marinated meat products; as well as d) quality implications of thermally-processed marinated meat products. In certain instances, either marination would aid heat processing or vice versa, while in others, thermal processing may well be detrimental to marination.

Practical application: The addition of marinades (marination process) are capable of enhancing the quality of meat products. The application of thermal processes in some instances may strengthen the efficacy of marinades.

Keywords: animal meat product; marination; herbs/spices; thermal treatment; product development

1. Introduction

Generally, meat products involve edible flesh/muscle tissues from certain domestic animals, which serve as food, ranging from bovine, porcine, ovine, and caprine animals, poultry (domestic and not domestic birds, excluding ratites), etc. (Cobos & Díaz, 2015). Globally, meat production would corroborate with the decreasing trend in all domestic animal species, which is believed to happen as animal farmers adapt to the self-consumption needs, alongside the limited market demands (Petroman et al., 2013). Typically, meat comprises approximately 72–75 % water, 21 % nitrogen-based compounds, 2.5–5 % lipids, 1 % non-nitrogenous compounds (vitamins), and carbohydrates, alongside about 1 % ash (potassium, phosphorus, sodium, chlorine, magnesium, calcium, and iron) (Cobos & Díaz, 2015). The variation of meat composition depends on influences from several factors like animal species, breed, sex, feeding, muscle, etc (Cobos & Díaz, 2015). Besides the global production of bovine, porcine, ovine, and caprine animals, including poultry that vary across continents, however, meeting the demands/needs of the ever increasing (global) population remains the focus. Meat/meat products remain a positive resource of bioactive compounds for human health. The growing consumer health awareness alongside intensifying global competition by meat producers cumulatively pressures the need for healthier products, especially targeting preservation strategies (Pogorzelska-Nowicka et al., 2018). Indeed, food preservation continually helps to strengthen the various meat processing strategies. Further, the preservation technology involves not only categories I and II (heat treatment), but also categories III and IV (shelf stability), which aim to either reduce water activity (drying, salting), combined effect of reducing both pH and water activity (fermented products). (Vandendriessche, 2008).

Prior to understanding the importance of thermal processes, especially when applied to marinated meat products, preservation needs of meat product still persist. In this, there are processing categories, which according to Hui (2012), would involve key steps like slaughtering, raw product, heat treated, fully cooked but not shelf stable, not heat treated but shelf stable, heat treated and shelf stable, as well as thermally processed and shelf sterile. From these, meat products that emerge can include cured/cooked-cured, fresh enhanced / comminuted/reformed, dried/dried fermented, as well as frozen types (Cobos & Díaz, 2015).

Nowadays, natural preservatives specifically involving marinades are being applied to meat products to enhance various quality attributes (Cheok et al., 2011;Istrati et al., 2015; Sokołowicz et al.,2021). In addition to how different herbs/plants are applied via marination to serve their purpose, the manner by which meat samples takes up marinade into its muscle depends on (meat) type, (marination) technique, and the duration of (marination) process (Siroli et al., 2020; Okpala et al., 2022). On the other hand, the advances of thermal processing over the decades has helped enhance the consumer edibility, decrease microbial proliferation and enhance flavor/texture of meat products. Examples of thermal processing include aseptic processing, cook-chill, grilling, laser-based packaging, ohmic heating, sous-vide, etc(Schellekens, & Martens, 1992; Viegas et al., 2012; Okpala et al., 2023). The advent of hurdle technology, alongside various conventional heat processing techniques and/or novel thermal processes would be combined and applied to marinated meat products. However, as published experimental/synthesised literature involving animal meat products, plant-based marination, and thermal processes continues to grow, there is need to supplement existing information. Therefore, this treatise aims to discuss how quality of animal meat products has been enhanced through plant-based marinations and thermal processes, drawing from a) plant-based marination: some key examples, and usefulness; b) marination/marinades: briefs on preparation and applications; c) major thermal processes applied to marinated meat products; as well as d) quality implications of thermally-processed marinated meat products.

2. Plant-based marination: some examples, and their potentials

The use of extracts from fruits, herbs, and plants gains popularity given consumers' desire for so-called "natural additives", the latter which refer to those naturally found with multiple attributed benefits (Balasundram et al., 2006; Lorenzo et al., 2018). As among very important alternatives to chemicals, plant sources remain increasingly applicable to meat products (Jayasena and Jo, 2013). Among several techniques being employed to increase the tenderness of meat, the marination approach appears very promising especially its capacity to enhance flavor and water-holding capacity (Vişan et al., 2021). Specifically, marination refers to the process of treating meat with a variety of herbs, spices, organic acids, salt, and oil in order to tenderize and improve its flavor (Roudbari et al., 2019; Meneses and Teixeira, 2022). When combined with other preservation methods, marination makes common foodborne bacteria more vulnerable (Meneses and Teixeira, 2022). Indeed, the composition of marinades would directly influence the efficacy of the marination process; hence considering the desired marinated product, either single or combined plants could be utilized. Previous studies of different plants/herbs employed for marination purposes are shown in Table 1. In addition to the garlic (*Allium sativum* L.), ginger (*Zingiber officinale*), pineapple (*Ananas comosus*), and rosemary (*Rosmarinus officinalis* L.)(as shown in Table 1), several plants and herbs have shown potential as meat-marinating ingredients.

Garlic is one of the most often used culinary flavoring components (Gokoglu et al., 2012). Numerous studies have shown that garlic may lower the population of *Streptococcus*, Klebsiella, Proteus, *Bacillus*, *Clostridium*, *E. coli*, *Salmonella*, *Staphylococcus*, and *Helicobacter pylori* (Ankri and Mirelman, 1999; Banerjee and Sarkar, 2003; Chen et al., 2018; Phan et al., 2019; Sivam, 2001). Garlic contains phenolic compounds considered to draw significant attention as antioxidants (Awuchi and Okpala, 2022). Numerous scientists used garlic-based marinades to enhance the quality and/or safety of meat products (Farhadian et al., 2012; Nurwantoro et al., 2015; Tkacz et al., 2021). Ginger is a significant root spice that is extensively utilized in the meat industry and in the culinary arts (He et al., 2015; White, 2007; Awuchi and Okpala, 2022). Moreover, ginger extract would incorporate the action of proteolytic enzyme zingibain, which could soften tough meat through a tenderizing impact(Hiemori-Kondo et al., 2022; Kaewthong et al., 2021). In addition to tenderizing meat, Putra et al., (2019) showed ginger juice to reduce the flavor and lipid breakdown of refrigerated Saanen crossbred-goat meat. Besides, by containing the proteolytic enzyme bromelain, pineapple is among fruits employed in the marination of meat products (Golden and Smith-Marshall, 2012; Kaewthong et al., 2021). Pineapple extract showed antibacterial action against *Staphylococcus aureus* given by bromelain molecule alongside phytochemical constituents, such as Vitamin C and flavonoid (Loon et al., 2018). Food processors may use pineapple extracts to boost the tenderness and customer acceptability of chicken meat (Abdel-Naeem et al., 2022). Marinating beef in pineapple puree could optimize tenderization and reduce cooking losses (Lawrence and Lawrence, 2021).

Rosemary extracts are widely used natural antioxidants (Cadun et al., 2008). It has been reported that rosemary contains antioxidants compounds including rosmanol, rosmariquinone, rosmaridiphenol, and carnosol that are up to four times as potent as butylated hydroxyanisole (BHA) and equivalent to butylated hydroxytoluene (BHT) (Martínez et al., 2019; Nakatani and Inatani, 1984). Among main marinating component, the bioactive compounds in rosemary extracts may possess antibacterial properties (Gazwi et al., 2020; Lenik et al., 2021; Rashidaie Abandansarie et al., 2019; Fellenberg et al., 2020; Lee et al., 2020; Shen et al., 2022). Other plant/herbs employed in marination, as shown in Table 1, include koruk, black pepper, garlic/onion, edible mushroom, red pepper, tomato, coriander, blackberry, pomegranate, rosehip and grape, as well as sweet basil (Sengun et al., 2020; Gibis and Weiss, 2012; Vişan et al., 2021;Kim et al., 2010; Fu et al., 2022;Patriani et al., 2021; Yu et al., 2023; Sengun et al., 2021; Testa et al., 2019). Green tea, white tea, yellow tea, oolong tea, dark tea, and black tea, lemon grass , turmeric, curry leaf, torch, hibiscus, Lemon, thyme, oregano, sage leaf, hop , licorice root, curcuma, clove bud , oregano leaf, and ajwain seed, as well as Bay leaf have also been reported (Sepahpour et al., 2018; Wang et al., 2018; Mahrour et al., 2003; Gokoglu et al., 2012;Rababah et al., 2011; Bilgin Fıçıcılar et al., 2018; Tarvainen et al., 2015; Gibis and Weiss, 2010).

Table 1. Previous studies of different plants/herbs employed for marination purposes

Plants/herbs	Study aim	Key findings	Reference
koruk	To test the efficacy of koruk products (koruk juice and dried koruk pomace) as a marination agent against high and low inoculum dosages of Escherichia coli, Listeria monocytogenes, and Salmonella Typhimurium inoculation on chicken flesh.	Total acidity /phenolic content of marinating solutions made with koruk juice and dried koruk pomace both boosted the efficacy of the marination process, which in turn increased the safety of poultry meat	(Sengun et al., 2020)
grape seed and rosemary extract	To assess the effectiveness of water-in-oil marinades with grape seed extract or oil marinades including rosemary extract to minimize heterocyclic amines accumulation in beef patties	Rosemary and grape seed extract dispersed in sunflower oil or a water-in-oil emulsion inhibited the formation of various heterocyclic amines	(Gibis and Weiss, 2012)
Black pepper, rosemary, oregano, thyme, basil, and ginger	To examine the nutritional, textural, and sensory effects of herbs and oils on Black Angus beef sirloin meat.	Aromatic herbs and cold-pressed oils improved the beef's aroma, taste, and texture (particularly tenderness and juiciness) after prolonged marination. Each aromatic plant and oil had a distinct polyphenolic profile.	(Vişan et al., 2021)

Garlic and onion	To assess the antioxidant and meat quality impacts of garlic and onion juices marinated at 3 or 6% for cold-storing fresh pork	The antioxidant activity of juices (garlic and onion) on fresh pork during storage depend on marinade concetration. All treated samples obtained greater scores for taste, juiciness, and tenderness than untreated samples	(Kim et al., 2010)
ginger and pineapple	To enhance the flavor of barbecued culed dairy goat using ginger and pineapple juices as well as sodium bicarbonate (SB)	Marinating dairy goat meat in pineapple juice and SB may result in a quality improvement.	(Kaewthong et al., 2021)
Australian garlic	To determine the Phytochemical Properties and Antimicrobial Activity of Australian Garlic Cultivars (*Allium sativum* L.)	Observed significant bioactive phytochemical variations among garlic cultivars and tissues (skin and cloves). Australian garlic skin and cloves contained more bioactive phytochemicals than imported commercial garlic.	(Phan et al., 2019)
edible mushroom	To evaluate qualitative characteristics, microstructure, and protein degradation of Pork longissimus dorsi marinated with edible mushroom powders	Mushroom-based marinade enhanced the water holding capacity and tenderness of pork samples, and minimized both Z-disk and M-line of pork sarcomere marinated with edible mushroom.	(Fu et al., 2022)

sweet basil	To identify the physical quality of local chicken through marination with sweet basil seasoning	Sweet basil may decrease the pH value, retain the water content, minimize cooking loss and drip loss, and promote meat tenderness.	(Patriani et al., 2021)
garlic, pepper, onion red pepper, and tomato	To examine the effects of numerous commercial marinades and sous-vide cooking on the color, tenderness, cooking loss, and flavor of semi-membranous cow muscles.	Sous-vide beef's eating quality, including tenderness, as enhanced by marinades containing red pepper, garlic, pepper, onion, and tomato.	(Tkacz et al., 2021)
coriander	To examine the impact of coriander root and leaf extract marinades on the development and prevention of polycyclic aromatic hydrocarbons in roasted duck wing.	Coriander root extract marinade inhibited the production of polycyclic aromatic hydrocarbons in roasted duck wings to a larger extent than coriander leaf extract marinade.	(Yu et al., 2023)
blackberry, pomegranate, rosehip and grape	To assess the impact of the marination procedure using fruit vinegar marination liquids on the quality and safety of meat	The most efficacious marinade for preventing pathogens was rosehip vinegar. *L. monocytogenes* was the pathogen most sensitive to marinating solutions, and rosehip vinegar effectively reduced the hardness of meat samples.	(Sengun et al., 2021)
Olive leaf	To explore the efficacy of olive leaf extract against a broad spectrum of food spoilage microorganisms and the usage of olive leaf extract as a preservative in the anchovy fillet marination process	Because the extract extends the shelf life of the product without changing its organoleptic properties, it might be used in the food sector as a natural antioxidant and antibacterial food additive.	(Testa et al., 2019)

Ginger, lemon grass , Turmeric, curry leaf, and torch	To examine the ability of Four herbs and spices to prevent the development of HCAs in grilled meat.	All spices/herbs, whether used alone or in combination, were observed to lower total HCA concentrations in marinated grilled beef	(Sepahpour et al., 2018)
green tea, white tea, yellow tea, oolong tea, dark tea, and black tea	To examine the prevalence of PAHs in charcoal-grilled chicken wings and the effect of six tea marinades and their fundamental components on the formation of polycyclic aromatic hydrocarbons	The most effective inhibitor of PAH formation was green tea.	(Wang et al., 2018)
Lemon, thyme, and rosemary	To determine how the microbiological profile and sensory quality of fresh chicken are affected by marinating the chicken in natural plant extracts prior to irradiation.	Irradiation had an additional impact, along with the marinade's effect, in lowering microbial proliferation during storage.	(Mahrour et al., 2003)
Tomato and garlic	To examine the impact that extracts of tomato and garlic have on preventing the oxidation of lipids in anchovies that have been marinated.	Both tomato and garlic extracts showed inhibitory impact on the lipid oxidation of marinated samples. However, tomato extract seemed more efficient over garlic extract in preventing lipid oxidation.	(Gokoglu et al., 2012)

Grape Seed and Green Tea	To examine the effect of natural extracts of green tea or commercial grape seed in combination with different concentrations of synthetic tert-methyl-butylhydroquinone on lipid oxidation and the redness of goat meats.	Plant extracts would substantially reduce lipid oxidation in goat meats, although grape seed extract enhanced redness, although green tea extract lowered it.	(Rababah et al., 2011)
Bay leaf and green tea	To analyse the microbiological, sensorial, and physical aspects of bay leaf and green ten extract marinades on anchovy	Green tea and bay leaf extract lowered the microbial load, TVB-N concentration, and TBARS (thiobarbituric acid reactive substance) level, despite the undesirable dark color it produced	(Bilgin Fıçıcılar et al., 2018)
Rosemary, oregano, sage leaf, hop , licorice root, curcuma, clove bud , oregano leaf, and ajwain seed	To investigate the impact of plant extracts high in carbon dioxide on the oxidation of triacylglycerol in Atlantic salmon during cooking and storage.	Marination with plant extracts could increase the fish shelf life, alongside positive impact of variety of plants as marinade components	(Tarvainen et al., 2015)
hibiscus	To investigate the feasibility of preventing the formation of HAAs in fried beef patties by employing marinades with varying concentrations of hibiscus extract.	Marinating meat using hibiscus extracts prior to frying may inhibit the formation of PhIP and MeIQx without negative impact to organoleptic characteristics.	(Gibis and Weiss, 2010)

3. Marination/marinades: Briefs on preparation and applications

To reiterate, the import of marination of meat products has traditionally been to improve flavor/ tenderness, as well as enhance product shelf life. Marination importantly targets to increase raw meat yield, which could provide advantages to consumers/producers, especially in attaining a juicier meat texture alongside reduced water loss during cooking (Alvarado and McKee, 2007). On one hand, herbs/spices and water are the two primary functional components of plant-based marinades. Improving the appearance and quality of meat product with range of flavors and aromas remain crucial when incorporating plants and herbs into marinade solutions. In addition, the antioxidant and antibacterial properties would vary with marinade compositions. To achieve, extracting the precise concentrations from herbs and spices by addition of water can be challenging. Further, the addition of water prior to marination compensates for the anticipated weight loss during cooking, hence to maximize product juiciness/yield(Xiong, 2005). Indeed, water acts as a carrier and dispersant for salt, phosphates, sugar, and water-soluble flavoring and coloring agents in the marinade (Zhang et al., 2022). When applied to the surface of meat in high concentrations, salt acts as a preservative by improving the flavor, increasing the amount of moisture that is retained, acting as a synergist with sodium tripolyphosphate to extract salt-soluble proteins, dehydrating the meat, and inhibiting the outgrowth of *Clostridium botulinum* (Keeton, 2001).

Major preparation steps of making a marinade is shown in Figure 1. This preparation steps, from assembly/collection of the herbs/spices from the source, through separation/ sorting, to the refrigerated storage, would vary depending factors such as location, culture/ traditions, the meat type to be marinated, availability of supporting ingredients/flavouring, and the period of use. Huffstetler (2020) demonstrated that despite the available bottled marinades found in various stores, consumers can make their own. Capably, the enzymes in marinades help to break down fibres, tenderise as well as add flavour to meat products. Largely, marinating process could resemble brining, wherein the latter has much less acid level. Also, marinating process would resemble pickling, wherein the latter requires longer periods. Major proportions of marinade constituents is shown in Figure 2. Besides the acid- and oil-based marinades, there is the culinary perspective that (marinade) ratio are necessary. Alongside, marinades are dependent on flavour profiles, which are guided by such key components like oils, Chili peppers, condiments, wine, vinegar, dairy, fruits, herbs/spices. Marinade times are also essential, which from culinary perspective, meats like beef, lamb could be as low as 2 h, and as high as 24 h, whereas poultry chicken/turkey could also be as low as 2 h, but as high as 6 h (The Culinary Pro, 2022).

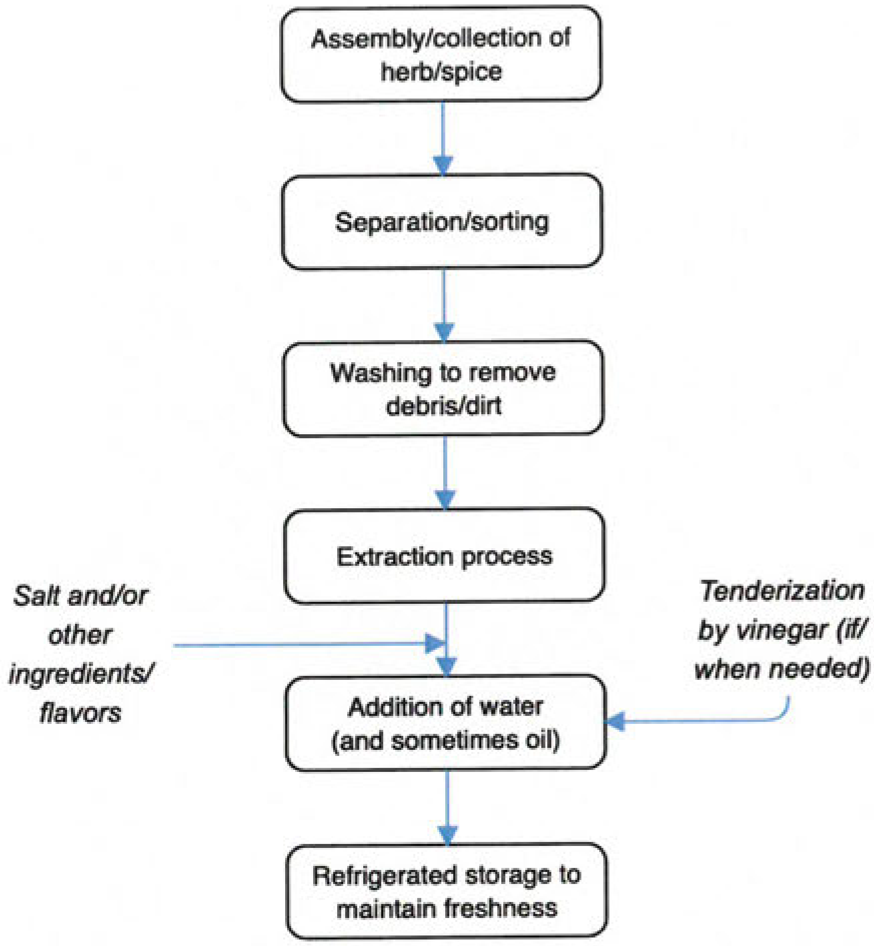

Figure 1: Major preparation steps of making a marinade

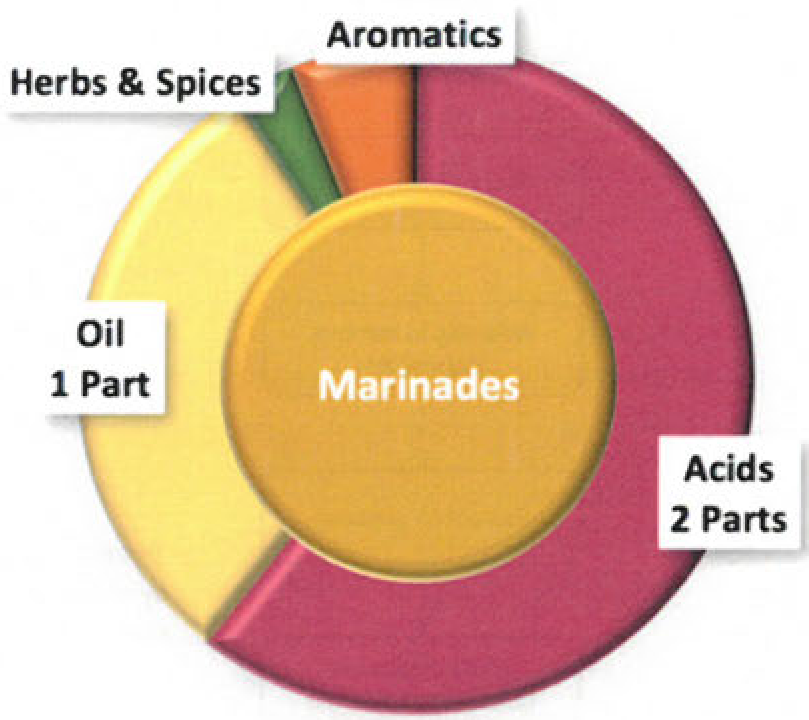

Figure 2: Major proportions of marinade constituents (Courtesy of The Culinary Pro)

Table 2 contains information on marinating techniques, mechanisms of action, benefits, and drawbacks. In the meat industry, there are a range of marinating techniques, including immersion, multi-needle injection, and tumbling, which are used to enhance the absorption of marinade into meat products. Specifically, each marination technique has specific benefits and drawbacks, and should be selected depending on the manufacturer's demands and the intended final product (Yusop et al., 2010). For instance, immersion or soaking requires the complete immersing of substrate in the marinade, to enable the liquid to permeate the meat through diffusion over a time, it may help achieve a greater quality enhancement of the product like in poultry(Yusop et al., 2010). The needle injection approach requires a strategy such that, as probes or needles are removed, the marinade would be injected, and as such, distributes it throughout the meat product (Yusop et al., 2012). The tumbling approach requires the marinating of poultry meat so as to provide a ready-to-cook, yet value-added output product. This involves the massaging and tumbling that bring about the extraction of protein exudates. The tumbling process leads to products with enhanced juiciness, and allows for improved slicing attributes (Alvarado and McKee, 2007). There could be the combination of injection process followed by tumbling process, which allows for the highest level of overall product improvement together with throughput of completed products in the shortest length of time (Oyetunji,2009; Williams, 2012).

Table 2. Marinating methods, merits and demerits

Methods	Mechanism of action	Merits	Demerits	References
Immersion or soaking	completely immersing the substrate in the marinade and enabling the liquid to permeate the meat through diffusion over a	Most affordable technique of marinating; No sophisticated equipment needed; suitable for home or small businesses	No uniformity in ingredient distribution, time-consuming, and a lower and slower marinade absorption rate.	(Yusop et al., 2010)
Injection	As the probes or needles are removed, the marinade is injected, distributing the marinade throughout the meat product	More relevant to the meat sector, better control over the marinating process by providing a precise amount of marinade solution, shorter time, and possibility to utilize the remaining marinade	Higher cooking losses, may create holes in the meat and allowing for leakage, a probable diminution in the meat's ability to retain water, and an increase in purging. expensive equipment, Not practical nor desirable for tiny	(Yusop et al., 2012)

Tumbling	Marinating poultry meat to provide a ready-to-cook, value-added product, which involves massaging and tumbling to bring about extraction of protein exudates, at either the food processing plant or the supermarket or butcher shop	Protein coagulates upon heating to improve binding properties. The extracted protein acts as a sealer, which facilitates the retention of moisture contained within the meat tissue	Increased initial equipment expenses, may tear fragments with poor size or utility, more aggressive to the muscle	(Alvarado and McKee, 2007)
Injection/ tumbling combination	Injection process followed by tumbling process	Delivers the highest level of overall product improvement and the highest throughput of completed products in the shortest length of time. Optimizes yields and weight gain while minimizing solution loss. Sensory quality improvement	Increased cost of equipments, increased manpower for product transfer and handling, can increase bacterial numbers	(Oyetunji,2009; Williams, 2012).

4. Some thermal processes applied to marinated meat products

Sous-vide

The cooking procedure is considered among ultimate factors in determining the final quality of meat products. An adequate choice of final thermal processing is crucial for beef tenderness, flavor, and juiciness, and that it should be selected uniquely for each (Guzek et al., 2015; Liu et al., 2020; Macharáková et al., 2021). Sous-vide cooking involves subjecting raw materials with intermediate foods to controlled conditions involving specific temperature and time (low-temperature long-time cooking method) within heat-stable vacuumized pouches (Schellekens, & Martens, 1992). Meat would be cooked at temperature ranges of between 55 and 95 °C for many hours to days, depending on its type, thickness, and connective tissue composition, and then rapidly cooled (Ayub and Ahmad, 2019; Baldwin, 2012; Ortuo et al., 2021).

Sous-vide preserves sensory quality, reduces lipid oxidation, extends shelf life, eliminates cooking losses, and increase the process yield by reducing material, labor, and storage expenses (Thathsarani et al., 2022). Sous-vide processing alone might not be sufficient to ensure the quality and safety of meat products for consumers. However, when combined with non-thermal processes like marination, the results of sous-vide cooking could further excel. This was proved by a number of workers (Haskaraca et al., 2019; Hong et al., 2016; Karyotis et al., 2017; Lee et al., 2021; Tkacz et al., 2022, 2021), who combined marination with sous-vide cooking to improve the quality and safety of different meat products. For instance, Haskaraca et al. (2019) proposed that marination with grapefruit seed extract in sous-vide-processed Doner Kebabs would increase the microbiological safety of these goods by inactivating *Listeria monocytogenes*, hence protecting public health. The addition of the marinade boosted the pathogen's sensitivity to heat throughout this phase. Another instance is Karyotis et al. (2017) who demonstrated that sous-vide cooking effectively eliminated *Listeria monocytogenes* and *Salmonella* spp. from marinated chicken breast.

Sous-vide applied to chicken breast with lime juice (as a marinade) enhanced the meat quality by suppressing the pink discolouration and bacterial development (Hong et al., 2016).

Probably, lime juice marinade might have contributed to preventing the pink-coloration of cooked sous-vide chicken breasts, by preserving their refrigerated freshness for up to 14 days. More so, the use of marinating process prior to the application of sous-vide cooking could improve the flavor, tenderness, and juiciness of beef meat(Tkacz et al.,2021). Red pepper, garlic, onion, and tomato-based marinades facilitated the beef steak production with promising quality attributes, such as high sensory scores, as well as reduced shear force, and cooking loss. Additionally, marinating would positively influence the fatty acid content of beef thereby enhancing the production of ready-to-eat meat products (Tkacz et al.,2021).

Boiling/steam cooking

Steaming, air-steaming, and superheated steaming are steam-based cooking procedures commonly employed in the meat sector (Barbanti and Pasquini, 2005; Bowker et al., 2018; Choi et al., 2016; Cho and Choi, 2021;Mudalal et al., 2014; O'Neill et al., 2019b; Modzelewska-Kapitu et al., 2019). Steam cooking has been modified from normal oven cooking process by injecting steam into the oven chamber to produce juicier meat products. Steam cooking occurs at a higher temperature than sous vide, ranging from 100 to 240 °C (Isleroglu et al., 2015), wherein the meat is cooked to the necessary temperature within a certain time period (Modzelewska-Kapitua et al., 2019). Steam cooking marinated pork chops under high pressure, examined by O'Neill et al. (2019b), showed improved physicochemical (cook loss, moisture content, WBSF, and n-6: n-3 PUFA ratio) and sensory (texture, tenderness, juiciness, and OSA) attributes. Kougiagka et al. (2022) examined the qualitative attributes of boiled snail fillets marinated with acids, salt, different oils, and spices. The hardness of the cylindrical mid-posterior region of the boiled snail fillet signaled the presence of the flesh fat and carbohydrate contents.

Elsewhere, Jiao et al.(2020) analyzed the nutritional and safety characteristics of Hengshan goat leg meat wherein processes like steaming, boiling, and braising produced meats were shown to enhance the balanced nutrients and reduce the carcinogens. Combining steam injection with air convection in the oven chamber can help to increase the tenderness and decrease the cooking losses of meat muscle (Murphy et al., 2001). Besides superheated steam and hot smoking (Cho and Choi, 2021) and microwave heating and steaming (Jantaranikorn et al., 2022), the combined use of marinating and air-steaming processing techniques for chicken breast meats, which result in minimal cooking loss and tenderized flesh, appear promising(Barbanti and Pasquini, 2005) and potentially improve proximate composition. Moreover, the extra sensible heat that comes from superheated steam (SS) can help elevate the anticipated temperature to surpass the saturation point at a given pressure (Cenkowski et al., 2007; Choi et al., 2016). Besides several cooking techniques on marinated chicken steak was evaluated, and it was found that chicken steak cooked with superheated steam had enhanced textural features and reduced cooking loss, as well as a greater overall acceptance than other cooking methods.

Grilling

Grilling, whether charcoal or oven grill type, involves a significant quantities of direct as well as radiant dry heat transferred by conduction (Schröder, 2003; Ježek et al., 2020; Liao et al., 2010), which when applied to animal meat products, produce considerable range of compounds that confers specific aroma, taste, and flavor (Tkacz & Modzelewska-Kapituła, 2022; Bassam, Noleto-Dias, &Farag, 2022). Like from a typical oven grill, such direct/ radiant heat would produce relatively high temperatures capable of facilitating the fat and juiciness loss (Beckett, 2012), as well as reducing the cooking time of any given meat slice(Schröder, 2003; Ježek et al., 2020). Largely, oven-grilling is considered healthier than the charcoal type, and increasingly of research food process interest particularly for animal/ meat food products(Okpala et al., 2022). Additionally, there is increasing evidence that the oven-grill approach appears increasingly employed across households in various parts of the globe, which suggests this facility as commercially and widely available. Hence, one would consider the application of oven grilling to animal meat products as recommendable (Okpala et al., 2023).

Previous studies on grilling marinated animal meat products have ranged from establishing the formation of heterocyclic amine carcinogen (Salmon, Knize, and Felton, 1997), polycyclic aromatic hydrocarbons(Viegas et al., 2014), reduction of carcinogenic heterocyclic aromatic amines (Viegas, Moreira, and Ferreira, 2015), to effects on quality attributes like nutritional, physicochemical, microstructural, and organoleptic/sensory attributes (Komoltri and Pakdeechanuan, 2012; Vidal et al., 2020; Okpala et al., 2022). For instance, Viegas, Moreira, and Ferreira(2015) investigated the effect of beer marinades in charcoal-grilled pork, specific to the formation of heterocyclic aromatic amines (HAs). These researchers showed beer marinades would mitigate the consumption impact of well-done grilled pork meat, thereby reducing the formation of cooking carcinogens. Moreover, Okpala et al.(2022) analyzed the antioxidant, organoleptic, and physicochemical changes in various marinated oven-grilled chicken breast meat samples. These workers showed oven-grilling method capable of moderating the antioxidant, organoleptic, and physicochemical value ranges in the various marinated chicken breast meat samples. Recently, Okpala et al. (2023) equally applied the combination of marination and oven-grilling to pork neck meat. The results showed a wide range of quality attributes, from the physicochemical to sensorial standpoints.

Roasting and frying

During this cooking process of frying, there is high temperature at normal air pressure and rapid heat transfer, which helps to make it efficient (Negara et al., 2021). Moreover, when considering frying , there can also improve the nutritional value, flavor, and sensory qualities of foods (Ziaiifar et al., 2008). Arcanjo et al. (2019) assessed the effect of wine marination on the degree of lipid and protein oxidation, volatiles profile, and sensory qualities of roasted beef strip steaks. In general, wine-based marination had a positive impact on the sensory qualities of roasted beef, lowering lipid oxidation and rancidity and providing fragrant esters, alcohols, and lactones. Al-Dalali et al.(2022a) studied the impact of frozen storage on the volatile aldehydes (VAs), volatile alcohols (VCs), lipid oxidation, and fatty acid content of marinated roasted beef was investigated. Marination of beef enhanced the amount of fatty acids and thiobarbituric acid-reactive chemicals, whilst the roasting procedure primarily contributed to the formation of several volatile compounds.

Using chemical and sensory evaluations, Al-Dalali et al. (2022b) showed the marination would enable various plants recipes to influence the taste profile of roasted beef flesh. Various marinade formulas would improve the aroma profile of roasted beef, especially in (marinade) solution comprising water, 2% salt, 0.5% sugar, 0.5% soy sauce, and spices. By the manufacture of braised pigeon, Qian et al.(2021) showed marinating and frying able to influence the taste of the flesh. By braising and frying, the amount and concentration of volatile compounds were significantly altered. In addition to some alkenes and alcohols been detected in marinated pigeon flesh, the frying activity enabled the Maillard process and fat oxidation to increase the formation of essential meat taste compounds such as benzaldehyde, phenylacetaldehyde, octanal, nonanal, heptanal, e-2-octenaldehyde, and others.

Microwave and ohmic heating

Providing significant commercial potential in the food processing business(Guo et al., 2017), microwave (MW) utilises a dielectric heating method alongside electromagnetic wave energy of between 0.3 and 300 GHz (Jiang et al., 2014). Food materials would absorb microwave energy that result in (microwave) attenuation (Xu et al., 2021). Indeed, the microwave concept has broad usage in the food sector, including cooking, pasteurization, drying, sterilizing, baking, etc (Chandrasekaran et al., 2013). Recent studies have shown microwave combined with other processing methods, and subsequently applied to marinated meat products (Jantaranikorn et al., 2022; Pankyamma et al., 2021; Wang et al., 2022). For instance, Wang et al. (2022) studied the flavor attributes of marinated pork belly cooked using conventional pan-heating, microwave heating, and microwave coupled with conduction heating. Microwave heating was shown to disrupt the integrity of the microstructure and increased cooking loss (50.33%) and sodium ion concentration (10.8 mg/g) by about 1.5 times that of microwave coupled with conduction heating. Also, microwave heating may expedite the breakdown of proteins and the thermal destruction of ribonucleotides, resulting in larger concentrations of free amino acids and nucleotides compared to conventional thermal heating. Pankyamma et al. (2021) investigated the effects of microwave power and drying techniques on the quality of tuna chunks marinated with salt, chili powder, turmeric powder, and pepper powder. The samples marinated and dried at 700 W displayed excellent rehydration capabilities and enhanced microbiological stability, although lipid oxidation was increased in the same samples.

Ohmic heating is a volume heating method that generates heat depending on the resistance of the material to the applied current (Zell et al., 2010). Also providing significant commercial potential in the food processing business, ohmic heating involves the conversion of dissipated electrical energy into heat elevates the system's temperature, prompting considerable changes in food material components and microstructure, such as protein denaturation and water migration(Ángel-Rendón et al., 2020; Gavahian et al., 2019). Given its quick processing time, ohmic heating would inhibit lipid/protein oxidation (Kang et al., 2021). The efficiency of ohmic heating relies on the composition and physical features of the given food item, particularly its electrical conductivity. (Varghese et al., 2014; Zell et al., 2009). By utilizing the benefits of ohmic heating, Kamonpatana and Sastry (2022) examined pretreatment methods aimed to both enhance and reduce the electrical conductivities of different solid particles, such as chicken chow mein ingredients. The electrical conductivity of chicken was most difficult to modify by blanching alone, necessitating marination in conductive fluids for the necessary durations. The impact of ohmic cooking on the water holding capacity, cooking loss, and color of marinated pork short shank was evaluated by ngel-Rendón et al. (2019). Ohmic cooking of pork might have advantages in the culinary trade owing to the shorter cooking durations that can be used without substantially impacting essential parameters such as cooking loss, color, and water holding capacity.

High hydrostatic and ultrasound techniques

Alongside the marination process, the incorporation of supplemental strategies to assure quality and enhance marinade absorption would require the effective utilization of available procedures. Retention as well as uptake of marinade could improve by combining with other technologies such as ultrasounds (Shi et al., 2020; Xiong et al., 2020) and high hydrostatic and hydrodynamic pressure (Bowker et al., 2010; O'Neill et al., 2019a), the latter probably effective in enhancing the marination process yield (Xu et al., 2019). By testing the effectiveness of high hydrostatic pressure in accelerating pork chop marinade absorption, O'Neill et al., (2019a) demonstrated 400 MPa could improve marinade absorption, hence enhance flavor acceptance. Depending on the pressure level used, the high hydrostatic pressure application improved the pork chops' shelf life; nevertheless, the texture was significantly impacted. Moreover, the marinade seemed to conceal the decolorization/ whitening impact of high hydrostatic pressure on raw meat. The utilization of hydrodynamic pressure processing increased the assessment factors of the marinating process, as indicated by Bowker et al. (2010). The hydrodynamic pressure treatment of turkey breasts resulted in better textural qualities with no adverse impacts on muscle color or water retention. Additionally, hydrodynamic pressure treatment boosted marinade absorption, processing yield, and the tenderness of the final cooked product (Xiong et al., 2020). Besides, the major impact of ultrasound coupled with sodium bicarbonate-assisted marination on chicken breast meat was the enhancement of meat tenderization, water holding capacity, and curing efficiency. Elsewhere, Shi et al.(2020) demonstrated that ultrasound coupled with marination procedure (using potassium alginate) may tenderise aged chicken breast flesh. By evaluating the softness of cooked meats, these workers detected reduced shear force, which helped to optimize the tenderness of aged chicken breast.

5. Some quality implications of thermally-processed marinated meat products

Typically, meat must be prepared before consumption. Thermal processes cause several positive effects on meat, including inactivation of anti-nutrient enzymes (Sobral et al., 2018), taste and flavor enhancement, microorganism destruction, shelf life extension, tenderness (Abdel-Naeem et al., 2021; Bognár, 1998), and improved digestibility (Rodriguez-

Estrada et al., 1997; Sobral et al., 2018). However, they also produce some negative effects like aromatic polycyclic hydrocarbons (APHs) (Onopiuk et al., 2021), and nutritional losses (Rodriguez-Estrada et al., 1997). Heterocyclic aromatic amines (HAAs) and polycyclic aromatic hydrocarbons (PAHs) are potential and confirmed carcinogens (Pogorzelska-Nowicka et al., 2022). Cooking reduces the nutritional value of meat by destroying some vitamins and minerals, decreasing the meat's moisture content, denaturing muscle proteins, and altering the structure of myofibrillar and connective tissue (Abdel-Naeem et al., 2021). In addition, heating accelerates lipid oxidation, particularly for PUFA fats, which are abundant in rabbit meat (Lopes et al., 2015). The method of thermal treatment, the cooking environment (dry or wet), cooking temperature, and cooking duration, significantly affects the above cited cooking changes (Combes et al., 2004). In this sense, red blood spots may be caused by the insufficient denature of blood residues in blood arteries owing to inadequate heat transfer (Sturkie, 2012). Potentially, thermal processes may also affect the number of antioxidants originally present in marinated beef (Thomas et al., 2010).

Inhibitions of carcinogens

Both heterocyclic amines (HAs) and polycyclic aromatic hydrocarbons (PAHs) are essential carcinogenic and poisonous substances that are mostly found in cooked protein-rich diets, particularly meat products (Hsu and Chen, 2020). Accordingly, plant-based marinades prior to cooking has been researched for their inhibiting effects (Bao et al., 2020; Gumus and Kizil, 2022; Khan et al., 2022, 2021; Macit and Kizil, 2022; Yu et al., 2023). For instance, Yu et al. (2023) examined the impact and principal constituents of coriander root and leaf extract marinades on the development and inhibition of PAHs in roasted duck wings. Coriander root extract was found to inhibit the development of PAHs in roasted duck wings more effectively than coriander leaf extract. Phenolic compounds in coriander marinades seemed most crucial in PAHs inhibition.

Khan et al. (2022) examined the impact of Za'atar marinades on the development of polar and non-polar HCAs in fried beef patties. The ideal marination durations seemed so when decrease HCA exposure happened, which provided healthier meat products, as well as to find potential, and novel food safety hazards. Production differences in HCAs seemed likely linked to natural antioxidants present in Za'atar, to boost oxidative activity, and result in reduction and/or synthesis of HCAs within the thermally processed meat. Bao et al. (2020) investigated the mechanism of black pepper's effect on HAAs in tilapia fillets cooked at various temperatures. Black pepper, often employed to enhance food taste, might lend its use in preparing fish given the HAA limitations. The addition of 1.0% black pepper largely inhibited total HAAs in the fried fish fillets; hence, capably enhancing quality/safety of fried aquatic muscle products. Moreover, olive leaf extract marinades (Macit and Kizil, 2022) and *Vaccinium myrtillus* L. extract marinades (Gumus and Kizil, 2022) possess significant inhibitory capacity on the formation of heterocyclic aromatic amines (HAAs) in pan-cooked salmon and chicken thigh meat, respectively.

Red blood spots

Consumers as well as relevant stakeholders in the animal meat industry consider the occurrence of red blood spots (RBS) as rare/unacceptable in commercially prepared food. This is largely because it indicates undercooked meat products (Bae et al., 2018; Smith and Northcutt, 2003). RBS is said to occur when red blood spot is detected inside/within transverse meat cuts. The most likely cause of this defect is when blood lingers within the vessels post-slaughter. The ingredients employed in marinade solutions may alter the thermal denaturation of hemoglobin (Hb), hence influencing the color of blood residues in vessels after cooking (Jantaranikorn and Yongsawatdigul, 2020). Further, in order to prevent apparition of red blood spots, marinated chicken breasts have to be cooked to an internal temperature of 85 °C for at least 1 min (Jantaranikorn and Yongsawatdigul, 2020). Moreover, the potential reduction of red blood spots in cooked marinated chicken breasts can occur using a combination of microwave heating and steaming(Jantaranikorn et al.,2022). Accordingly, microwave pre-heating for 7 min, followed by steaming to a core temperature of 82°C seems an effective heating technique for lowering RBS incidence, alongside reasonable cooking loss. Consequently, heat processes may decrease red blood spots during the marination.

Loss of nutrients

Thermal processes may affect the nutritional composition of meat and fish, including water content, lipid profile, amino acids, and bioactive components such as vitamins and polyphenols, therefore impacting the quality of the final product (Ersoy and Ozeren, 2009; Garcia-Segovia et al., 2007; Jensen et al., 2014). Preventing nutrient loss should be a target, and that appears to be a promising take away the use of marinades/margination process provides when applied to meat products, prior to thermal treatment. For instance, Xie et al. (2022b) studied the effects of tea polyphenol (TP) treatments (control, unmarinated, and marinated) on the lipid oxidation of scallop adductor muscle during hot air drying. Marinating scallops in tea polyphenols enhanced the antioxidant activity, prevented lipid oxidation, and preserved the scallops' nutritional content throughout drying. Another instance is the work of Xie et al. (2022a) that showed the marination with bamboo leaves might suppress lipoxygenase activity and interfere with free radical chain reaction. Moreover, Okpala et al. (2022) analyzed the antioxidant, organoleptic, and physicochemical changes in various marinated oven-grilled chicken breast meat. Oven-grilling method, by moderating the antioxidant, organoleptic, and physicochemical value ranges in the various marinated chicken breast meat samples, may well be controlling the loss of nutrients.

6. Concluding remarks

This current treatise has provided relevant information about how quality of animal meat products would be enhanced through combination of plant-based marinations and thermal processes. Indeed, marination demonstrates great promise to increase the tenderness of meat, as well as enhance the flavor and water-holding capacity. Moreover, the intention of novel thermal processing technologies remains to fulfil the expectations of customers but to a certain degree. From this synthesis, the addition of marinades (marination process) was shown as a key to enhance quality of meat products. Promisingly, the application of thermal processes would go further to strengthen the marinades' efficacy. The direction of future work could be further literature synthesis involving systematic or meta-analysis of animal meat products that have been subjected to combination of marinades/marination with thermal processing. Conducting such systematic or meta-analysis would help reveal new understanding of existing data especially the effectiveness and efficacy of combination of marinades/marination with thermal processing.

Acknowledgements

Authors CORO, and MK acknowledge financial support from Wroclaw University of Environmental and Life Sciences, Poland. Author RPFG acknowledges financial support from Polytechnic Institute of Viseu, Portugal.

Funding

The APC is financed by Wrocław University of Environmental and Life Sciences, Poland. Publication financed by the project UPWR 2.0: international and interdisciplinary program of development of Wrocław University of Environmental and Life Sciences, co-financed by the European Social Fund under the Operational Program Knowledge Education Development, under contract No. POWR.03.05.00-00-Z062/18 of June 4, 2019.

Authorship contribution

Conceptualization, CORO, and MIH; Data curation, CORO, and MIH; Formal analysis, CORO, and MIM; Funding acquisition, CORO, and MK; Investigation, CORO, and MIH; Methodology, CORO, and MIH; Project administration, and supervision, MK and RPFG; Validation, and visualization, MK and RPFG; Writing – original draft, CORO, and MIH; Writing – review & editing, CORO, MK and RPFG. All authors reviewed and approved the final manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

Abdel-Naeem, H.H.S., Abdelrahman, A.G., Imre, K., Morar, A., Herman, V., Yassien, N.A., 2022. Improving the Structural Changes, Electrophoretic Pattern, and Quality Attributes of Spent Hen Meat Patties by Using Kiwi and Pineapple Extracts. Foods 11, 3430. https://doi.org/10.3390/foods11213430

Abdel-Naeem, H.H.S., Sallam, K.I., Zaki, H.M.B.A., 2021. Effect of different cooking methods of rabbit meat on topographical changes, physicochemical characteristics, fatty acids profile, microbial quality and sensory attributes. Meat Sci. 181, 108612. https://doi.org/10.1016/j.meatsci.2021.108612

Al-Dalali, S., Li, C., Xu, B., 2022a. Insight into the effect of frozen storage on the changes in volatile aldehydes and alcohols of marinated roasted beef meat: Potential mechanisms of their formation. Food Chem. 385, 132629. https://doi.org/10.1016/j.foodchem.2022.132629

Al-Dalali, S., Li, C., Xu, B., 2022b. Evaluation of the effect of marination in different seasoning recipes on the flavor profile of roasted beef meat via chemical and sensory analysis. J. Food Biochem. 46, e13962. https://doi.org/10.1111/jfbc.13962

Alvarado, C., McKee, S., 2007. Marination to Improve Functional Properties and Safety of Poultry Meat. J. Appl. Poult. Res. 16, 113–120. https://doi.org/10.1093/japr/16.1.113

Ángel-Rendón, S.V., Filomena-Ambrosio, A., Cordon-Díaz, S., Benítez-Sastoque, E.R., Sotelo-Díaz, L.I., 2019. Ohmic cooking: Application of a novel technology in pork and influences on water holding capacity, cooking loss and colour. Int. J. Gastron. Food Sci. 17, 100164. https://doi.org/10.1016/j.ijgfs.2019.100164

Ángel-Rendón, S.V., Filomena-Ambrosio, A., Hernández-Carrión, M., Llorca, E., Hernando, I., Quiles, A., Sotelo-Díaz, I., 2020. Pork meat prepared by different cooking methods. A microstructural, sensorial and physicochemical approach. Meat Sci. 163, 108089. https://doi.org/10.1016/j.meatsci.2020.108089

Ankri, S., Mirelman, D., 1999. Antimicrobial properties of allicin from garlic. Microbes Infect. 1, 125–129. https://doi.org/10.1016/S1286-4579(99)80003-3

Arcanjo, N.M., Ventanas, S., González-Mohíno, A., Madruga, M.S., Estévez, M., 2019. Benefits of wine-based marination of strip steaks prior to roasting: inhibition of protein oxidation and impact on sensory properties. J. Sci. Food Agric. 99, 1108–1116. https://doi.org/10.1002/jsfa.9278

Awuchi, C.G.; Okpala, C.O.R. (2022). Natural nutraceuticals, especially functional foods, their ma-jor bioactive components, formulation, and health benefits for disease prevention-An overview. J. Food Bioact. 19, 97–123.

Ayub, H., Ahmad, A., 2019. Physiochemical changes in sous-vide and conventionally cooked meat. Int. J. Gastron. Food Sci. 17, 100145. https://doi.org/10.1016/j.ijgfs.2019.100145

Bae, S.M., Cho, M.G., Hong, G.T., Jeong, J.Y., 2018. Effect of NaCl Concentration and Cooking Temperature on the Color and Pigment Characteristics of Presalted Ground Chicken Breasts. Korean J. Food Sci. Anim. Resour. 38, 417–430. https://doi.org/10.5851/kosfa.2018.38.2.417

Balasundram, N., Sundram, K., Samman, S., 2006. Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem. 99, 191–203. https://doi.org/10.1016/j.foodchem.2005.07.042

Baldwin, D.E., 2012. Sous vide cooking: A review. Int. J. Gastron. Food Sci. 1, 15–30. https://doi.org/10.1016/j.ijgfs.2011.11.002

Banerjee, M., Sarkar, P., 2003. Inhibitory effect of garlic on bacterial pathogens from spices. World J. Microbiol. Biotechnol. 19, 565–569. https://doi.org/10.1023/A:1025108116389

Bao, X., Miao, J., Fan, Y., Lai, K., 2020. The effective inhibition of the formation of heterocyclic aromatic amines via adding black pepper in fried tilapia fillets. J. Food Process. Preserv. 44, e14435. https://doi.org/10.1111/jfpp.14435

Barbanti, D., Pasquini, M., 2005. Influence of cooking conditions on cooking loss and tenderness of raw and marinated chicken breast meat. LWT - Food Sci. Technol. 38, 895–901. https://doi.org/10.1016/j.lwt.2004.08.017

Bassam, S.M., Noleto-Dias, C., Farag, M.A. (2022). Dissecting grilled red and white meat flavor: Its characteristics, production mechanisms, influencing factors and chemical hazards. Food Chem 371, 131139.

Beckett, F. (2012). Sausage & Mash; Bloomsbury Publishing: London, UK, p. 160, ISBN 9781408187760

Bilgin Fıçıcılar, B., Gençcelep, H., Özen, T., 2018. Effects of bay leaf (Laurus nobilis) and green tea (Camellia sinensis) extracts on the physicochemical properties of the marinated anchovies with vacuum packaging. CyTA - J. Food 16, 848–858. https://doi.org/10.1080/19476337.2018.1485747

Bognár, A., 1998. Comparative study of frying to other cooking techniques influence on the nutritive value. Grasas Aceites 49, 250–260. https://doi.org/10.3989/gya.1998.v49.i3-4.746

Bowker, B.C., Callahan, J.A., Solomon, M.B., 2010. Effects of hydrodynamic pressure processing on the marination and meat quality of turkey breasts1. Poult. Sci. 89, 1744–1749. https://doi.org/10.3382/ps.2009-00484

Bowker, B.C., Maxwell, A.D., Zhuang, H., Adhikari, K., 2018. Marination and cooking performance of portioned broiler breast fillets with the wooden breast condition. Poult. Sci. 97, 2966–2970. https://doi.org/10.3382/ps/pey144

Cadun, A., Kışla, D., Çaklı, Ş., 2008. Marination of deep-water pink shrimp with rosemary extract and the determination of its shelf-life. Food Chem. 109, 81–87. https://doi.org/10.1016/j.foodchem.2007.12.021

Cenkowski, S., Pronyk, C., Zmidzinska, D., Muir, W.E., 2007. Decontamination of food products with superheated steam. J. Food Eng., Future of Food Engineering 83, 68–75. https://doi.org/10.1016/j.jfoodeng.2006.12.002

Chandrasekaran, S., Ramanathan, S., Basak, T., 2013. Microwave food processing—A review. Food Res. Int. 52, 243–261. https://doi.org/10.1016/j.foodres.2013.02.033

Chen, C., Liu, C.-H., Cai, J., Zhang, W., Qi, W.-L., Wang, Z., Liu, Z.-B., Yang, Y., 2018. Broad-spectrum antimicrobial activity, chemical composition and mechanism of action of garlic (Allium sativum) extracts. Food Control 86, 117–125. https://doi.org/10.1016/j.foodcont.2017.11.015

Cheok, C. Y., Chin, N. L., Yusof, Y. A., Mustapa Kamal, S. M., & Sazili, A. Q. (2011). Effect of marinating temperatures on physical changes of traditionally marinated beef satay. *Journal of Food Processing and Preservation*, *35*(4), 474-482. https://doi.org/10.1111/j.1745-4549.2010.00490.x

Cho, W.-H., Choi, J.-S., 2021. Sensory Quality Evaluation of Superheated Steam-Treated Chicken Leg and Breast Meats with a Combination of Marination and Hot Smoking. Foods 10, 1924. https://doi.org/10.3390/foods10081924

Choi, Y.-S., Hwang, K.-E., Jeong, T.-J., Kim, Y.-B., Jeon, K.-H., Kim, E.-M., Sung, J.-M., Kim, H.-W., Kim, C.-J., 2016. Comparative Study on the Effects of Boiling, Steaming, Grilling, Microwaving and Superheated Steaming on Quality Characteristics of Marinated Chicken Steak. Korean J. Food Sci. Anim. Resour. 36, 1–7. https://doi.org/10.5851/kosfa.2016.36.1.1

Cobos, Á., & Díaz, O. (2015). Chemical composition of meat and meat products. *Chapter 16, In: P.C.K. Cheung, B.M. Mehta (eds.), Handbook of Food Chemistry,* Springer-Verlag Berlin Heidelberg, pp. 471-510, DOI 10.1007/978-3-642-36605-5_6, .

Combes, S., Lepetit, J., Darche, B., Lebas, F., 2004. Effect of cooking temperature and cooking time on Warner–Bratzler tenderness measurement and collagen content in rabbit meat. Meat Sci. 66, 91–96. https://doi.org/10.1016/S0309-1740(03)00019-6

Demir, H., Yıldız, M.K., Becerikli, İ., Unluturk, S., Kaya, Z., 2020. Impact of Pasteurization Process on the Quality and Marination Properties of Onion Juice. Turk. J. Agric. - Food Sci. Technol. 8, 531–537. https://doi.org/10.24925/turjaf.v8i3.531-537.2715

Ersoy, B., Özeren, A., 2009. The effect of cooking methods on mineral and vitamin contents of African catfish. Food Chem. 115, 419–422. https://doi.org/10.1016/j.foodchem.2008.12.018

Farhadian, A., Jinap, S., Faridah, A., Zaidul, I.S.M., 2012. Effects of marinating on the formation of polycyclic aromatic hydrocarbons (benzo[a]pyrene, benzo[b]fluoranthene and fluoranthene) in grilled beef meat. Food Control 28, 420–425. https://doi.org/10.1016/j.foodcont.2012.04.034

Fellenberg, M.A., Carlos, F., Peña, I., Ibáñez, R.A., Vargas-Bello-Pérez, E., 2020. Oxidative quality and color variation during refrigeration (4 °C) of rainbow trout fillets marinated with different natural antioxidants from oregano, quillaia and rosemary. Agric. Food Sci. 29, 43–54. https://doi.org/10.23986/afsci.87078

Fu, Q., Shi, H., Hu, D., Cheng, J., Chen, S., Ben, A., 2022. Pork longissimus dorsi marinated with edible mushroom powders: Evaluation of quality traits, microstructure, and protein degradation. Food Res. Int. 158, 111503. https://doi.org/10.1016/j.foodres.2022.111503

Garcia-Segovia, P., Andres-Bello, A., Martinez-Monzo, J., 2007. Effect of cooking method on mechanical properties, color and structure of beef muscle (M. pectoralis). J. Food Eng.

Gavahian, M., Tiwari, B.K., Chu, Y.-H., Ting, Y., Farahnaky, A., 2019. Food texture as affected by ohmic heating: Mechanisms involved, recent findings, benefits, and limitations. Trends Food Sci. Technol. 86, 328–339. https://doi.org/10.1016/j.tifs.2019.02.022

Gazwi, H.S.S., Mahmoud, M.E., Hamed, M.M., 2020. Antimicrobial activity of rosemary leaf extracts and efficacy of ethanol extract against testicular damage caused by 50-Hz electromagnetic field in albino rats. Environ. Sci. Pollut. Res. 27, 15798–15805. https://doi.org/10.1007/s11356-020-08111-w

Gibis, M., Weiss, J., 2012. Antioxidant capacity and inhibitory effect of grape seed and rosemary extract in marinades on the formation of heterocyclic amines in fried beef patties. Food Chem. 134, 766–774. https://doi.org/10.1016/j.foodchem.2012.02.179

Gibis, M., Weiss, J., 2010. Inhibitory effect of marinades with hibiscus extract on formation of heterocyclic aromatic amines and sensory quality of fried beef patties. Meat Sci. 85, 735–742. https://doi.org/10.1016/j.meatsci.2010.03.034

Gokoglu, N., Yerlikaya, P., Topuz, O.K., 2012. Effects of Tomato and Garlic Extracts on Oxidative Stability in Marinated Anchovy. J. Food Process. Preserv. 36, 191–197. https://doi.org/10.1111/j.1745-4549.2011.00576.x

Golden, K.D., Smith-Marshall, J., 2012. Characterization of Bromelain from *Morinda citrifolia* (Noni). J. Sci. Res. 4, 445–445. https://doi.org/10.3329/jsr.v4i2.8125

Gómez, I., Janardhanan, R., Ibañez, F.C., Beriain, M.J., 2020. The Effects of Processing and Preservation Technologies on Meat Quality: Sensory and Nutritional Aspects. Foods 9, 1416. https://doi.org/10.3390/foods9101416

Gumus, D., Kizil, M., 2022. Reduction of heterocyclic aromatic amines formation in chicken thigh meat by Vaccinium myrtillus L. extract. J. Food Process. Preserv. 46, e17119. https://doi.org/10.1111/jfpp.17119

Guo, Q., Sun, D.-W., Cheng, J.-H., Han, Z., 2017. Microwave processing techniques and their recent applications in the food industry. Trends Food Sci. Technol. 67, 236–247. https://doi.org/10.1016/j.tifs.2017.07.007

Haskaraca, G., Juneja, V.K., Mukhopadhyay, S., Kolsarici, N., 2019. The effects of grapefruit seed extract on the thermal inactivation of Listeria monocytogenes in sous-vide processed döner kebabs. Food Control 95, 71–76. https://doi.org/10.1016/j.foodcont.2018.07.006

He, F.-Y., Kim, H.-W., Hwang, K.-E., Song, D.-H., Kim, Y.-J., Ham, Y.-K., Kim, S.-Y., Yeo, I.-J., Jung, T.-J., Kim, C.-J., 2015. Effect of Ginger Extract and Citric Acid on the Tenderness of Duck Breast Muscles. Korean J. Food Sci. Anim. Resour. 35, 721–730. https://doi.org/10.5851/kosfa.2015.35.6.721

Hiemori-Kondo, M., Ueta, R., Nagao, K., 2022. Improving deer meat palatability by treatment with ginger and fermented foods: A deer meat heating study. Int. J. Gastron. Food Sci. 29, 100577. https://doi.org/10.1016/j.ijgfs.2022.100577

Hong, G.-E., Mandal, P.K., Kim, J.-H., Park, W.-J., Oh, J.-W., Lim, K.-W., Lee, C.-H., 2016. Influence of Lime Juice on the Pink Discoloration and Quality of Sous-Vide Processed Chicken Breast During Refrigerated Storage. J. Food Qual. 39, 726–731. https://doi.org/10.1111/jfq.12230

Hsu, K.-Y., Chen, B.-H., 2020. Analysis and reduction of heterocyclic amines and cholesterol oxidation products in chicken by controlling flavorings and roasting condition. Food Res. Int. 131, 109004. https://doi.org/10.1016/j.foodres.2020.109004

Huffstetler, E. (2020). How to Make Your Own Marinade. In "Condiments & Sauces",https://www.thespruceeats.com/make-your-own-marinade-1388463, Accessed 14 December 2022

Hui, Y.H. (Ed.) (2012). Handbook of Meat and Meat Processing. 2nd Edition, Boca Raton, FL: CRC Press (Taylor and Francis Group), ISBN: 978-1-4398-3864-2, pp. 979.

Isleroglu, H., Kemerli, T., Kaymak-Ertekin, F., 2015. Effect of Steam-Assisted Hybrid Cooking on Textural Quality Characteristics, Cooking Loss, and Free Moisture Content of Beef. Int. J. Food Prop. 18, 403–414. https://doi.org/10.1080/10942912.2013.833219

Istrati, D., Simion Ciuciu, A. M., Vizireanu, C., Ionescu, A., & Carballo, J. (2015). Impact of Spices and Wine-Based Marinades on Tenderness, Fragmentation of Myofibrillar Proteins and Color Stability in Bovine *Biceps Femoris* Muscle. *Journal of Texture Studies*, *46*(6), 455-466. https://doi.org/10.1111/jtxs.12144

Jantaranikorn, M., Thumanu, K., Yongsawatdigul, J., 2022. Reduction of red blood spots in cooked marinated chicken breast meat by combined microwave heating and steaming. Poult. Sci. 102317. https://doi.org/10.1016/j.psj.2022.102317

Jantaranikorn, M., Yongsawatdigul, J., 2020. Effect of marinating ingredients on temperature-induced denaturation of hemoglobin and its relation to red blood spot formation in cooked chicken breast. J. Food Sci. 85, 2398–2405. https://doi.org/10.1111/1750-3841.15308

Jayasena, D.D., Jo, C., 2013. Essential oils as potential antimicrobial agents in meat and meat products: A review. Trends Food Sci. Technol. 34, 96–108. https://doi.org/10.1016/j.tifs.2013.09.002

Jensen, I.-J., Dort, J., Eilertsen, K.-E., 2014. Proximate composition, antihypertensive and antioxidative properties of the semi-membranosus muscle from pork and beef after cooking and in vitro digestion. Meat Sci. 96, 916–921. https://doi.org/10.1016/j.meatsci.2013.10.014

Ježek, F.; Kameník, J.; Macharáčková, B.; Bogdanovičová, K.; Bednár, J. (2020). Cooking of meat: Effect on texture, cooking loss and microbiological quality—A review. Acta Vet. Brno 2020, 88, 487–496

Jiang, H., Zhang, M., Mujumdar, A.S., Lim, R.-X., 2014. Comparison of drying characteristic and uniformity of banana cubes dried by pulse-spouted microwave vacuum drying, freeze drying and microwave freeze drying. J. Sci. Food Agric. 94, 1827–1834. https://doi.org/10.1002/jsfa.6501

Jiao, Y., Liu, Y., Quek, S.Y., 2020. Systematic evaluation of nutritional and safety characteristics of Hengshan goat leg meat affected by multiple thermal processing methods. J. Food Sci. 85, 1344–1352. https://doi.org/10.1111/1750-3841.15087

Kaewthong, P., Wattanachant, C., Wattanachant, S., 2021. Improving the quality of barbecued culled-dairy-goat meat by marination with plant juices and sodium bicarbonate. J. Food Sci. Technol. 58, 333–342. https://doi.org/10.1007/s13197-020-04546-8

Kamonpatana, P., Sastry, S.K., 2022. Electrical conductivity of foods and food components: The influence of formulation processes. J. Food Process Eng. 45, e13992. https://doi.org/10.1111/jfpe.13992

Kang, D., Zhang, W., Lorenzo, J.M., Chen, X., 2021. Structural and functional modification of food proteins by high power ultrasound and its application in meat processing. Crit. Rev. Food Sci. Nutr. 61, 1914–1933. https://doi.org/10.1080/10408398.2020.1767538

Karyotis, D., Skandamis, P.N., Juneja, V.K., 2017. Thermal inactivation of Listeria monocytogenes and Salmonella spp. in sous-vide processed marinated chicken breast. Food Res. Int. 100, 894–898. https://doi.org/10.1016/j.foodres.2017.07.078

Keeton, J.T., 2001. Formed and emulsion products, in: Poultry Meat Processing. CRC Press.

Khan, M.R., Busquets, R., Azam, M., 2021. Blueberry, raspberry, and strawberry extracts reduce the formation of carcinogenic heterocyclic amines in fried camel, beef and chicken meats. Food Control 123, 107852. https://doi.org/10.1016/j.foodcont.2020.107852

Khan, M.R., Samdani, M.S., Alam, M.G., Alammari, A.M., Azzam, M.A., Ali, H.M., Alsohaimi, I.H., Azam, M., Ouladsmane, M., Alam, P., 2022. Inhibitory effect of culinary herbs Za'atar (blend of thyme, sesame seeds and sumac) marinades on the formation of polar and non-polar heterocyclic amines carcinogen in fried beef patties: Determination by SPE/UPLC-MS/MS. J. King Saud Univ. - Sci. 34, 101821. https://doi.org/10.1016/j.jksus.2022.101821

Kim, Y.J., Jin, S.K., Park, W.Y., Kim, B.W., Joo, S.T., Yang, H.S., 2010. THE EFFECT OF GARLIC OR ONION MARINADE ON THE LIPID OXIDATION AND MEAT QUALITY OF PORK DURING COLD STORAGE: EFFECT OF GARLIC OR ONION MARINADE ON PORK QUALITY. J. Food Qual. 33, 171–185. https://doi.org/10.1111/j.1745-4557.2010.00333.x

Komoltri, P., & Pakdeechanuan, P. (2012). Effects of marinating ingredients on physicochemical, microstructural and sensory properties of golek chicken

Kougiagka, E., Apostologamvrou, C., Hatziioannou, M., Giannouli, P., 2022. Quality characteristics and microstructure of boiled snail fillet meat. J. Food Process. Preserv. 46, e17079. https://doi.org/10.1111/jfpp.17079

Lawrence, M.T., Lawrence, T.E., 2021. At-home methods for tenderizing meat using blade tenderization, lime juice and pineapple puree. Meat Sci. 176, 108487. https://doi.org/10.1016/j.meatsci.2021.108487

Lee, B., Park, C.H., Kim, J.Y., Hyeonbin, O., Kim, D., Cho, D.K., Kim, Y.S., Choi, Y.M., 2021. Effects of Astragalus membranaceus, Adenophora triphylla, and Ulmus pumila Extracts on Quality Characteristics and Storage Stability of Sous-Vide Cooked Chicken Breasts. Food Sci. Anim. Resour. 41, 664–673. https://doi.org/10.5851/kosfa.2021.e24

Lee, S.Y., Yim, D.G., Lee, D.Y., Kim, O.Y., Kang, H.J., Kim, H.S., Jang, A., Park, T.S., Jin, S.K., Hur, S.J., 2020. Overview of the effect of natural products on reduction of potential carcinogenic substances in meat products. Trends Food Sci. Technol. 99, 568–579. https://doi.org/10.1016/j.tifs.2020.03.034

Lešnik, S., Furlan, V., Bren, U., 2021. Rosemary (Rosmarinus officinalis L.): extraction techniques, analytical methods and health-promoting biological effects. Phytochem. Rev. 20, 1273–1328. https://doi.org/10.1007/s11101-021-09745-5

Liao, G.; Wang, G.; Xu, X.; Zhou, G. (2010). Effect of cooking methods on the formation of heterocyclic aromatic amines in chicken and duck breast. Meat Sci. 85, 149–154

Loon, Y.K., Satari, M.H., Dewi, W., 2018. Antibacterial effect of pineapple (Ananas comosus) extract towards Staphylococcus aureus. Padjadjaran J. Dent. 30, 1–6. https://doi.org/10.24198/pjd.vol30no1.16099

Lopes, A.F., Alfaia, C.M.M., Partidário, A.M.C.P.C., Lemos, J.P.C., Prates, J.A.M., 2015. Influence of household cooking methods on amino acids and minerals of Barrosã-PDO veal. Meat Sci. 99, 38–43. https://doi.org/10.1016/j.meatsci.2014.08.012

Lorenzo, J.M., Pateiro, M., Domínguez, R., Barba, F.J., Putnik, P., Kovačević, D.B., Shpigelman, A., Granato, D., Franco, D., 2018. Berries extracts as natural antioxidants in meat products: A review. Food Res. Int. 106, 1095–1104. https://doi.org/10.1016/j.foodres.2017.12.005

Macit, A., Kizil, M., 2022. Effect of olive leaf extract marination on heterocyclic aromatic amine formation in pan-fried salmon. J. Sci. Food Agric. 102, 3908–3915. https://doi.org/10.1002/jsfa.11740

MAHROUR, A., CAILLET, S., NKETSA-TABIRI, J., LACROIX, M., 2003. Microbial and Sensory Quality of Marinated and Irradiated Chicken. J. Food Prot. 66, 2156–2159. https://doi.org/10.4315/0362-028X-66.11.2156

Martínez, L., Castillo, J., Ros, G., Nieto, G., 2019. Antioxidant and Antimicrobial Activity of Rosemary, Pomegranate and Olive Extracts in Fish Patties. Antioxidants 8, 86. https://doi.org/10.3390/antiox8040086

Meneses, R., Teixeira, P., 2022. Marination as a Hurdle to Microbial Pathogens and Spoilers in Poultry Meat Products: A Brief Review. Appl. Sci. 12, 11774. https://doi.org/10.3390/app122211774

Modzelewska-Kapituła, M., Pietrzak-Fiećko, R., Tkacz, K., Draszanowska, A., Więk, A., 2019. Influence of sous vide and steam cooking on mineral contents, fatty acid composition and tenderness of semimembranosus muscle from Holstein-Friesian bulls. Meat Sci. 157, 107877. https://doi.org/10.1016/j.meatsci.2019.107877

Mudalal, S., Petracci, M., Tappi, S., Rocculi, P., Cavani, C., 2014. Comparison between the Quality Traits of Phosphate and Bicarbonate-Marinated Chicken Breast Fillets Cooked under Different Heat Treatments. Food Nutr. Sci. 2014. https://doi.org/10.4236/fns.2014.51005

Murphy, R.Y., Johnson, E.R., Duncan, L.K., Clausen, E.C., Davis, M.D., March, J.A., 2001. Heat Transfer Properties, Moisture Loss, Product Yield, and Soluble Proteins in Chicken Breast Patties During Air Convection Cooking. Poult. Sci. 80, 508–514. https://doi.org/10.1093/ps/80.4.508

Nakatani, N., Inatani, R., 1984. Two Antioxidative Diterpenes from Rosemary (Rosmarinus officinalis L.) and a Revised Structure for Rosmanol†. Agric. Biol. Chem. 48, 2081–2085. https://doi.org/10.1080/00021369.1984.10866436

Negara, B.F.S.P., Tirtawijaya, G., Cho, W.-H., Harwanto, D., Sohn, J.-H., Kim, J.-S., Choi, J.-S., 2021. Effects of Frying Processes on the Nutritional and Sensory Characteristics of Different Mackerel Products. Processes 9, 1645. https://doi.org/10.3390/pr9091645

Nurwantoro, Bintoro, V.P., Legowo, A.M., Purnomoadi, A., Setiani, B.E., 2015. Garlic Antioxidant (Allium Sativum L.) to Prevent Meat Rancidity. Procedia Food Sci., 3, 137–141. https://doi.org/10.1016/j.profoo.2015.01.014

Okpala, C.O.R., Juchniewicz, S., Leicht, K., Korzeniowska, M., Guiné, R.P.F., 2022. Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods 11, 3951. https://doi.org/10.3390/foods11243951

Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470.

O'Neill, C.M., Cruz-Romero, M.C., Duffy, G., Kerry, J.P., 2019a. Improving marinade absorption and shelf life of vacuum packed marinated pork chops through the application of high pressure processing as a hurdle. Food Packag. Shelf Life 21, 100350. https://doi.org/10.1016/j.fpsl.2019.100350

O'Neill, C.M., Cruz-Romero, M.C., Duffy, G., Kerry, J.P., 2019b. Comparative effect of different cooking methods on the physicochemical and sensory characteristics of high pressure processed marinated pork chops. Innov. Food Sci. Emerg. Technol. 54, 19–27. https://doi.org/10.1016/j.ifset.2019.03.005

Onopiuk, A., Kołodziejczak, K., Szpicer, A., Wojtasik-Kalinowska, I., Wierzbicka, A., Półtorak, A., 2021. Analysis of factors that influence the PAH profile and amount in meat products subjected to thermal processing. Trends Food Sci. Technol. 115, 366–379. https://doi.org/10.1016/j.tifs.2021.06.043

Ortuño, J., Mateo, L., Rodríguez-Estrada, M.T., Bañón, S., 2021. Effects of sous vide vs grilling methods on lamb meat colour and lipid stability during cooking and heated display. Meat Sci. 171, 108287. https://doi.org/10.1016/j.meatsci.2020.108287

Oyetunji, O. T. (2009). Evaluation of the effect of marination processes on the quality and safety of pork products (Doctoral dissertation, University of Georgia).

Pankyamma, V., Madhusudana Rao, B., Debbarma, J., Pallela Panduranga Naga, V., 2021. Physicochemical, microstructural, and microbial qualities of dehydrated Tuna chunks: Effects of microwave power and drying methods. J. Food Process. Preserv. 45, e15426. https://doi.org/10.1111/jfpp.15426

Patriani, P., Hafid, H., Sepriadi, S., 2021. The effect of marination using sweet basil (Ocimum basilicum) spices on the physical quality of local chicken meat. IOP Conf. Ser. Earth Environ. Sci. 782, 022075. https://doi.org/10.1088/1755-1315/782/2/022075

Petroman, C., Petroman, I., Negruţ, V., Marin, D., Ciolac, R., & Văduva, L. (2013). Frequency of Consumption of Meat and Meat Products in Timis County. *Scientific Papers: Animal Science & Biotechnologies/Lucrari Stiintifice: Zootehnie si Biotehnologii*, *46*(2).

Phan, A., Netzel, G., Chhim, P., Netzel, M., Sultanbawa, Y., 2019. Phytochemical Characteristics and Antimicrobial Activity of Australian Grown Garlic (Allium Sativum L.) Cultivars. Foods 8, 358. https://doi.org/10.3390/foods8090358

Pogorzelska-Nowicka, E., Kurek, M., Hanula, M., Wierzbicka, A., Półtorak, A., 2022. Formation of Carcinogens in Processed Meat and Its Measurement with the Usage of Artificial Digestion—A Review. Molecules 27, 4665. https://doi.org/10.3390/molecules27144665

Pogorzelska-Nowicka, E., Atanasov, A. G., Horbańczuk, J., & Wierzbicka, A. (2018). Bioactive compounds in functional meat products. *Molecules*, *23*(2), 30

Putra, A.A., Wattanachant, S., Wattanachant, C., 2019. Sensory-related Attributes of Raw and Cooked Meat of Culled Saanen Goat Marinated in Ginger and Pineapple Juices. Trop. Anim. Sci. J. 42, 59–67. https://doi.org/10.5398/tasj.2019.42.1.59

Qian, M., Zheng, M., Zhao, W., Liu, Q., Zeng, X., Bai, W., 2021. Effect of marinating and frying on the flavor of braised pigeon. J. Food Process. Preserv. 45. https://doi.org/10.1111/jfpp.15219

Rababah, T.M., Ereifej, K.I., Alhamad, M.N., Al-Qudah, K.M., Rousan, L.M., Al-Mahasneh, M.A., Al-u'datt, M.H., Yang, W., 2011. Effects of Green Tea and Grape Seed and TBHQ on Physicochemical Properties of Baladi Goat Meats. Int. J. Food Prop. 14, 1208–1216. https://doi.org/10.1080/10942911003637327

Rashidaie Abandansarie, S.S., Ariaii, P., Charmchian Langerodi, M., 2019. Effects of encapsulated rosemary extract on oxidative and microbiological stability of beef meat during refrigerated storage. Food Sci. Nutr. 7, 3969–3978. https://doi.org/10.1002/fsn3.1258

Rodriguez-Estrada, M.T., Penazzi, G., Caboni, M.F., Bertacco, G., Lercker, G., 1997. Effect of different cooking methods on some lipid and protein components of hamburgers. Meat Sci. 45, 365–375. https://doi.org/10.1016/S0309-1740(96)00123-4

Salmon, C. P., Knize, M. G., & Felton, J. S. (1997). Effects of marinating on heterocyclic amine carcinogen formation in grilled chicken. *Food and Chemical Toxicology*, *35*(5), 433-441.

Schellekens, W., & Martens, T. (1992). Sous Vide Cooking Part I: Scientific Literature Review; Commission of the European Communities Directorate General XII. Research And Development.

Schröder, M.J. (2003). Food Quality and Consumer Value: Delivering Food that Satisfies; Springer: Berlin, Germany, p. 150, ISBN 3540439145.

Sengun, I.Y., Kilic, G., Ozturk, B., 2020. The effects of koruk products used as marination liquids against foodborne pathogens (Escherichia coli O157:H7, Listeria monocytogenes and Salmonella Typhimurium) inoculated on poultry meat. LWT 133, 110148. https://doi.org/10.1016/j.lwt.2020.110148

Sengun, I.Y., Yildiz Turp, G., Cicek, S.N., Avci, T., Ozturk, B., Kilic, G., 2021. Assessment of the effect of marination with organic fruit vinegars on safety and quality of beef. Int. J. Food Microbiol. 336, 108904. https://doi.org/10.1016/j.ijfoodmicro.2020.108904

Sepahpour, S., Selamat, J., Khatib, A., Manap, M.Y.A., Abdull Razis, A.F., Hajeb, P., 2018. Inhibitory effect of mixture herbs/spices on formation of heterocyclic amines and mutagenic activity of grilled beef. Food Addit. Contam. Part A 35, 1911–1927. https://doi.org/10.1080/19440049.2018.1488085

Shen, X., Huang, X., Tang, X., Zhan, J., Liu, S., 2022. The Effects of Different Natural Plant Extracts on the Formation of Polycyclic Aromatic Hydrocarbons (PAHs) in Roast Duck. Foods 11, 2104. https://doi.org/10.3390/foods11142104

Shi, H., Zhang, X., Chen, X., Fang, R., Zou, Y., Wang, D., Xu, W., 2020. How ultrasound combined with potassium alginate marination tenderizes old chicken breast meat:

Possible mechanisms from tissue to protein. Food Chem. 328, 127144. https://doi.org/10.1016/j.foodchem.2020.127144

Siroli, L., Baldi, G., Soglia, F., Bukvicki, D., Patrignani, F., Petracci, M., & Lanciotti, R. (2020). Use of essential oils to increase the safety and the quality of marinated pork loin. *Foods*, *9*(8), 987. Sivam, G.P., 2001. Protection against Helicobacter pylori and Other Bacterial Infections by Garlic. J. Nutr. 131, 1106S-1108S. https://doi.org/10.1093/jn/131.3.1106S

Smith, D.P., Northcutt, J.K., 2003. Red Discoloration of Fully Cooked Chicken Products. J. Appl. Poult. Res. 12, 515–521. https://doi.org/10.1093/japr/12.4.515

Sobral, M.M.C., Cunha, S.C., Faria, M.A., Ferreira, I.M., 2018. Domestic Cooking of Muscle Foods: Impact on Composition of Nutrients and Contaminants. Compr. Rev. Food Sci. Food Saf. 17, 309–333. https://doi.org/10.1111/1541-4337.12327

Sokołowicz, Z., Augustyńska-Prejsnar, A., Krawczyk, J., Kačániová, M., Kluz, M., Hanus, P., & Topczewska, J. (2021). Technological and Sensory Quality and Microbiological Safety of RIR Chicken Breast Meat Marinated with Fermented Milk Products. *Animals*, *11*(11), 3282.

Sturkie, P.D., 2012. Avian Physiology. Springer Science & Business Media.

Tarvainen, M., Nuora, A., Quirin, K.-W., Kallio, H., Yang, B., 2015. Effects of CO2 plant extracts on triacylglycerol oxidation in Atlantic salmon during cooking and storage. Food Chem. 173, 1011–1021. https://doi.org/10.1016/j.foodchem.2014.10.125

Testa, B., Lombardi, S.J., Macciola, E., Succi, M., Tremonte, P., Iorizzo, M., 2019. Efficacy of olive leaf extract (Olea europaea L. cv Gentile di Larino) in marinated anchovies (Engraulis encrasicolus, L.) process. Heliyon 5, e01727. https://doi.org/10.1016/j.heliyon.2019.e01727

Thathsarani, A.P.K., Alahakoon, A.U., Liyanage, R., 2022. Current status and future trends of sous vide processing in meat industry; A review. Trends Food Sci. Technol. 129, 353–363. https://doi.org/10.1016/j.tifs.2022.10.009

Tkacz K, Modzelewska-Kapituła M. 2022. Marinating and Grilling as Methods of Sensory Enhancement of Sous Vide Beef from Holstein-Friesian Bulls. Applied Sci. 12(20):10411. https://doi.org/10.3390/app122010411

The Culinary Pro (2022). Marinades, https://www.theculinarypro.com/marinades, Accessed 14 December 2022

Thomas, R.H., Bernards, M.A., Drake, E.E., Guglielmo, C.G., 2010. Changes in the antioxidant activities of seven herb- and spice-based marinating sauces after cooking. J. Food Compos. Anal. 23, 244–252. https://doi.org/10.1016/j.jfca.2009.08.019

Tkacz, K., Modzelewska-Kapituła, M., Petracci, M., Zduńczyk, W., 2021. Improving the quality of sous-vide beef from Holstein-Friesian bulls by different marinades. Meat Sci. 182, 108639. https://doi.org/10.1016/j.meatsci.2021.108639

Tkacz, K., Tylewicz, U., Pietrzak-Fiećko, R., Modzelewska-Kapituła, M., 2022. The Effect of Marinating on Fatty Acid Composition of Sous-Vide Semimembranosus Muscle from Holstein-Friesian Bulls. Foods 11, 797. https://doi.org/10.3390/foods11060797

Vandendriessche, F. (2008). Meat products in the past, today and in the future. *Meat science*, *78*(1-2), 104-113.

Varghese, K.S., Pandey, M.C., Radhakrishna, K., Bawa, A.S., 2014. Technology, applications and modelling of ohmic heating: a review. J. Food Sci. Technol. 51, 2304–2317. https://doi.org/10.1007/s13197-012-0710-3

Vidal, N. P., Manful, C., Pham, T. H., Wheeler, E., Stewart, P., Keough, D., & Thomas, R. (2020). Novel unfiltered beer-based marinades to improve the nutritional quality, safety, and sensory perception of grilled ruminant meats. *Food Chemistry*, *302*, 125326.

Viegas, O., Amaro, L. F., Ferreira, I. M., & Pinho, O. (2012). Inhibitory effect of antioxidant-rich marinades on the formation of heterocyclic aromatic amines in pan-fried beef. *Journal of agricultural and food chemistry*, *60*(24), 6235-6240. https://doi.org/10.1021/jf302227b

Viegas, O., Yebra-Pimentel, I., Martinez-Carballo, E., Simal-Gandara, J., & Ferreira, I. M. (2014). Effect of beer marinades on formation of polycyclic aromatic hydrocarbons in charcoal-grilled pork. *Journal of agricultural and food chemistry*, *62*(12), 2638-2643.

Viegas, O., Moreira, P. S., & Ferreira, I. M. (2015). Influence of beer marinades on the reduction of carcinogenic heterocyclic aromatic amines in charcoal-grilled pork meat. *Food Additives & Contaminants: Part A*, *32*(3), 315-323.

Vişan, V.-G., Chiş, M.S., Păucean, A., Mureşan, V., Puşcaş, A., Stan, L., Vodnar, D.C., Dulf, F.V., Ţibulcă, D., Vlaic, B.A., Rusu, I.E., Kadar, C.B., Vlaic, A., 2021. Influence of Marination with Aromatic Herbs and Cold Pressed Oils on Black Angus Beef Meat. Foods 10, 2012. https://doi.org/10.3390/foods10092012

Wang, C., Xie, Y., Qi, J., Yu, Y., Bai, Y., Dai, C., Li, C., Xu, X., Zhou, G., 2018. Effect of Tea Marinades on the formation of polycyclic aromatic hydrocarbons in charcoal-grilled chicken wings. Food Control 93, 325–333. https://doi.org/10.1016/j.foodcont.2017.12.010

Wang, Xingwei, Feng, T., Wang, Xuejiao, Xia, S., Yu, J., Zhang, X., 2022. Microwave heating and conduction heating pork belly: Non-volatile compounds and their correlation with taste characteristics, heat transfer modes, and matrix microstructure. Meat Sci. 192, 108899. https://doi.org/10.1016/j.meatsci.2022.108899

Williams, J. B. (2012). Marination: Processing technology. Handbook of meat and meat processing. CRC Press, Boca Raton, FL, 495-504.

Xie, H., Chen, H., Yuechen, L., Fan, F., 2022a. Effects of Different Antioxidants of Bamboo Leaves Treatments on Lipid Oxidation of Scallop (Argopecten irradians) Adductor Muscle During Hot Air Drying. J. Aquat. Food Prod. Technol. 31, 939–950. https://doi.org/10.1080/10498850.2022.2119910

Xie, H., Yue, C., Fan, F., 2022b. Different tea polyphenol treatments on lipid oxidation of scallop (Argopecten irradians) adductor muscle during hot air drying. J. Food Process. Preserv. 46, e16534. https://doi.org/10.1111/jfpp.16534

Xiong, G., Fu, X., Pan, D., Qi, J., Xu, X., Jiang, X., 2020. Influence of ultrasound-assisted sodium bicarbonate marination on the curing efficiency of chicken breast meat. Ultrason. Sonochem. 60, 104808. https://doi.org/10.1016/j.ultsonch.2019.104808

Xiong, Y.L., 2005. Role of myofibrillar proteins in water-binding in brine-enhanced meats. Food Res. Int., Food of the 21st Century: Safety & Health 38, 281–287. https://doi.org/10.1016/j.foodres.2004.03.013

Xu, H., Zhang, X.-K., Wang, X., Liu, D.-H., 2019. The effects of high pressure on the myofibrillar structure and meat quality of marinating Tan mutton. J. Food Process Eng. 42, e13138. https://doi.org/10.1111/jfpe.13138

Xu, J., Zhang, M., Wang, Y., Bhandari, B., 2021. Novel Technologies for Flavor Formation in the Processing of Meat Products: A Review. Food Rev. Int. 1–25. https://doi.org/10.1080/87559129.2021.1926480

Yu, Y., Cheng, Y., Wang, C., Huang, S., Lei, Y., Huang, M., Zhang, X., 2023. Inhibitory effect of coriander (Coriandrum sativum L.) extract marinades on the formation of polycyclic aromatic hydrocarbons in roasted duck wings. Food Sci. Hum. Wellness 12, 1128–1135. https://doi.org/10.1016/j.fshw.2022.10.038

Yusop, S.M., O'Sullivan, M.G., Kerry, J.F., Kerry, J.P., 2012. Influence of processing method and holding time on the physical and sensory qualities of cooked marinated chicken breast fillets. LWT - Food Sci. Technol. 46, 363–370. https://doi.org/10.1016/j.lwt.2011.08.007

Yusop, S.M., O'Sullivan, M.G., Kerry, J.F., Kerry, J.P., 2010. Effect of marinating time and low pH on marinade performance and sensory acceptability of poultry meat. Meat Sci. 85, 657–663. https://doi.org/10.1016/j.meatsci.2010.03.020

Zell, M., Lyng, J.G., Cronin, D.A., Morgan, D.J., 2010. Ohmic cooking of whole beef muscle — Evaluation of the impact of a novel rapid ohmic cooking method on product quality. Meat Sci. 86, 258–263. https://doi.org/10.1016/j.meatsci.2010.04.007

Zell, M., Lyng, J.G., Cronin, D.A., Morgan, D.J., 2009. Ohmic heating of meats: Electrical conductivities of whole meats and processed meat ingredients. Meat Sci. 83, 563–570. https://doi.org/10.1016/j.meatsci.2009.07.005

Zhang, J., Bowker, B., Yang, Y., Pang, B., Yu, X., Tasoniero, G., Zhuang, H., 2022. Water properties and marinade uptake in broiler pectoralis major with the woody breast condition. Food Chem. 391, 133230. https://doi.org/10.1016/j.foodchem.2022.133230

Ziaiifar, A.M., Achir, N., Courtois, F., Trezzani, I., Trystram, G., 2008. Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. Int. J. Food Sci. Technol. 43, 1410–1423. https://doi.org/10.1111/j.1365-2621.2007.01664.x

04 czerwca 2023 r
(miejscowość i data)

Charles Odilichukwu R. OKPALA…
Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych
Wydział Biotechnologii i Nauk o Żywności
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (Accepted for publication).Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. Food Science and Technology (Campinas)…*. mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

04 June 2023……………
data i podpis

…MSc Mouanhde Imamou Hassani…. 03 kwietnia 2023 r

imię i nazwisko (miejscowość i data)

INRAPE- Moroni BP 1406, Comoros….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (Accepted for publication).Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. Food Science and Technology (Campinas)….* mój udział polegał na brał udział w opracowaniu literatury oraz walidacji/wizualizacji danych.

13 April 2023

……………………………………

data i podpis

dr hab Małgorzata Korzeniowska, prof. uczelni

03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (Accepted for publication). Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. Food Science and Technology (Campinas),* mój udział polegał na uczestnictwie w konceptualizacji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

…Prof Dr. hab. Raquel P.F. Guine…. 01 czerwca 2023 r

imię i nazwisko (miejscowość i data)

Polytechnic Institute of Viseu, Portugal….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Imamou Hassani, M., Korzeniowska, M., & Guiné, R. P. F. (Accepted for publication).Enhancing the quality of animal meat products by combining plant-based marinations and thermal processes: A treatise. Food Science and Technology (Campinas)….* mój udział współnadzorował prace projektowe, udzielał wglądu w metodologię, uczestniczył w walidacji/wizualizacji danych oraz w rewizji projektu pracy .

15 May 2023

Raquel Guiné

……………………………………

data i podpis

frontiers in Nutrition

PERSPECTIVE
published: 13 November 2020
doi: 10.3389/fnut.2020.578941

Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios

Charles Odilichukwu R. Okpala and Małgorzata Korzeniowska*

Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland

Quality attributes in agrofood products can be somewhat difficult to identify and observe. The quality of the same agrofood product in two different market shelves would, most likely not be exactly the same when compared to each other, even if both belong to the same batch. There are quality attributes peculiar/specific to one product, which stands it unique from the other. The basics/fundamentals underlying such peculiarities/specificities can be found either in concept, content, and context perspectives of quality. It appears however that no publication has deliberated on these three aspects together, that is, concept, content, and context perspectives of quality of agrofood products, particularly on how it contributes to the decision-making to purchase an agrofood product. We, therefore, in this current work, looked at concept, content, and context perspectives of quality of agrofood products, specifically discussing some reflections on some consumer decision-making purchase scenarios. Each of these, "concept," "content," and "context" perspectives independently project very important meanings to the quality of agrofood products. There appears a thin line that would separate concept, content, and context perspectives of quality in the choice/decision-making of purchase of agrofood products. To solely depend on either concept, content, or context perspective of quality will likely provide the consumer with insufficient information about the (given/specific) agrofood product. Interaction between any two will most likely improve the information. Obviously, the interaction between the three, would most likely provide sufficient information about the quality and help consumers make a more informed decision of purchase.

Keywords: agrofood product, agrofood industry, interaction, information, decision-making, consumer quality

OPEN ACCESS

Edited by:
Kannan R. R. Rengasamy, North-West University, South Africa

Reviewed by:
Mona Elena Popa, University of Agronomic Sciences and Veterinary Medicine, Romania
Chunpeng Wan, Jiangxi Agricultural University, China

****Correspondence:***
Charles Odilichukwu R. Okpala
charlesokpala@gmail.com

Specialty section:
This article was submitted to Nutrition and Food Science Technology, a section of the journal Frontiers in Nutrition

Received: *01 July 2020*
Accepted: *10 September 2020*
Published: *13 November 2020*

Citation:
Okpala COR and Korzeniowska M (2020) Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. Front. Nutr. 7:578941. doi: 10.3389/fnut.2020.578941

INTRODUCING QUALITY IN AGROFOOD PRODUCTS

Quality should neither be perceived as a physical entity or instance with a fixed position in space and time, nor a scientific or technical word (1–3). Quality, the very useful idea in general life and management (3), represents a set of characteristics of a product (or service) that provides some ability/potential to meet up with consumers' expressed/implied needs (4). However, quality attributes in agrofood products can be somewhat difficult to identify and observe (5). To either envisage or picture the quality particularly in terms of the composition of properties, however, the differences in quality can potentially depict either: (1) changes in the markedness of one or more properties in quantity (vertical/product modification of quality), (2) decreases/extensions in the values (horizontal product modification), or (3) changes in how value associates with single components (consumer induced quality change) (6). Whilst the estimates of quality of a given agrofood product can be drawn up either objectively or subjectively (7), such (estimates) can equally vary either from location-to-location and or by product-to-product, owing to the complex nature of the (agrofood) global supply chain (8).

QUALITY: FROM AGROFOOD PRODUCT TO INDUSTRY—A FEW HIGHLIGHTS

Quality is an essential element of any existing economic activity, with a direct impact on consumer, producer, and product/service (9). Information asymmetry between buyers and sellers of agrofood products can complicate the buyer's ability to identify with quality and assert guarantees in an institutional form, especially in such situation(s) where there is a need to counteract the effects of quality identification, as well as uncertainty. Besides, a contractual definition of quality would focus on the transition between the buyer and the seller of an agrofood product (5). Nonetheless, quality—an objective continually sought for within the agrofood industry—can be seen in three distinct perspectives, namely: (1) consumer perspective—understanding quality based on experience over time via dimensions of risk and trust; (2) institutional perspective—the use of objective/regulated indicators to define quality largely based on hygiene requirements; and (3) producers' perspective—where both raw materials and production methods help to define the quality of agrofood products (10–12). Moreover, quality can plausibly help in opening up discussions about agrofood products among key supply chain stakeholders, which in the broader sense would be contributing to food standard authorities/boards in building regulatory frameworks. Considering its fluid-/socially constructed nature, quality from the content and context standpoints appears to be with increasing emphasis across the globe. Quality, as an essential strategy for the future development of the farming/food industry, has similarly been echoed by the various agrofood product actors/stakeholders (13).

SOME CONSUMER-RELATED AGROFOOD PRODUCT QUALITY CHALLENGES, AND PROBLEMS

Meeting the prerequisite product quality benchmark/standard always remains among the key challenges for the agrofood product industry. Indeed, the quality of agrofood products is differentiated by a wide array of factors. The diverse differences in shelf-life time, cost, seasonality, level of processing required to make the product either fit for consumption or increase consumer appeal, degree of freshness especially for those ready after harvest, etc., are among the many factors that individually and or collectively challenge the resultant quality of agrofood products. Consumers have no alternative but to grapple with these diverse factors that affect quality, which are largely done through physical observations prior to making the appropriate decision on whether to purchase the agrofood product(s) or not. According to Dequiedt (14), how consumers see quality attributes of an agrofood product largely rely on three major facets, namely: (1) the experiences acquired after consumption, (2) how consumers search for it (the agrofood product), and (3) the credence associated with it (the agrofood product), which may not always be discovered either before or after its purchase.

Widely understood, the quality of the same agrofood product would likely not be exactly the same in one market shelf compared to the other. Such (quality) differences in agrofood products by markets (shelves) might likely underscore the problems that emanate from how quality is produced, revealed, and certified (14). For example, how quality produced could pose problems is when the same agrofood product from one producer meets the expectations/requirements of one set of consumers but not so for the other because of differences in quality, potentially attributable to variants in emphasis on quality. In addition, how quality revealed could pose problems is if the same agrofood product in two different market shelves differ by price because of differences in quality, wherein the higher quality is pricier than the lesser quality (15). In addition, how quality is certified could pose problems if the third-party mechanisms that facilitate truthful elevation of product (quality) information, allows a given (set of) agrofood product(s) that is clearly of a substandard quality to enter into the market (14). The previously mentioned quality challenges, potentially, could be compromising the consumers' integrity and trust of the agrofood product supply chain. And if such were to worsen, it might likely cumulate into complicated/complex short- and long-term conflicts/problems within the agrofood product supply chain. One can only imagine a conflict in the quality price of agrofood products. In addition, one can only imagine substandard quality agrofood products finding its way into the market shelves. Notably, a substandard agrofood product can potentially pose some health risk to consumers, especially after the "best before" dates (16, 17).

JUSTIFICATION OF THIS PERSPECTIVE PAPER

Mindful of the previously mentioned consumer-quality related challenges, when a consumer in a supermarket, for example, is about to purchase a given agrofood product, whether it is a bunch of bananas, some fresh tomatoes, fresh fish/meat, tinned fish, or even a loaf of bread, "quality" and its related aspects would most likely be considered. In each given/selected (agro)food product, there are associated quality attributes peculiar/specific to one product, which stands it unique from the other. Also, how Person A will perceive the quality of the same agrofood product will likely not be the same as Person B. The basics/fundamentals underlying such peculiarities/specificities, we believe, can be found either in concept, content, and context perspectives of quality. Therefore, how do these three ideas/perspectives of quality function/operate when a consumer is about to purchase an agrofood product? Do these three ideas/perspectives function/operate independently or interactively? How do these three ideas/perspectives independently or interactively drive consumers in their decision-making to purchase an agrofood product? It appears, however, that no publication has deliberated on these three aspects together, that is, concept, content, and context perspectives of quality of agrofood products, particularly on how it contributes to the decision-making of purchase an agrofood product. We, therefore, in this current work, looked at concept, content, and context perspectives of quality of agrofood products, specifically discussing some reflections on some consumer decision-making purchase scenarios. Subsequent sections will be structured in two parts, namely: (1) concept, content, and context perspectives of quality of agrofood products; and (2) reflections on some consumer decision-making-purchase scenarios, which can be commonly found.

CONCEPT, CONTENT, AND CONTEXT PERSPECTIVES OF AGROFOOD PRODUCT QUALITY

Concept Perspective of Quality

"Concept" can be defined simply as a principle or idea, an idea for a new product, and about a particular subject (18). Therefore, the concept of quality can be seen as an idea concerning the function/value ascribed to the character/property of, as in this case, the agrofood product. It can also involve, not only the origin of the product but also how hygienic and safe the food product is (6). It can also provide an avenue to interpret ideas surrounding quality, very applicable to any given agrofood product. As a benchmark to either recognize or separate an agrofood product based on predetermined specification(s), the concept perspective of quality can be either established or identified at any stage of the production/supply chain. In this case, a high level of precaution would have to be applied so as to ensure the consistency of quality control either along with or on each production line/stage (6).

Adapting from de Heer et al. (19) and Mogezomp et al. (20), such terms like "improved," "optimized," and "perfect" can be ascribed to the "concept" of quality, which can be applied to agrofood products. If that is to be the situation, "improved" can be when the product has received some added value over a premium one, "optimized" can be based on achieving an enhancement peak on either one or more of the specific product properties, and "perfect" can be when product characteristics attained peak consistently with 100% market response over a substantial time period. The concept perspective of quality can, therefore, be quantified when it gets allocated with a numerical value, which can help generate a "quality" type of data. It is on this basis that the concept perspective of quality plays a useful role in the food industry, to either create or determine the level of consumer acceptability on a given agrofood product (6). Besides being among the most widely studied issues in agriculture, the concept perspective of quality might closely associate with hygiene/health and natural condition of agrofood products (10, 12). Based on the existing food production structures, the creation of new concepts can therefore take place. This would allow the quality of selected/specific (agrofood) products to undergo a (healthy) market competition with another competing similar one, in order to sustain the eventual/overall image of "quality" (of these products) (6).

A consumer looking at an agrofood product in a supermarket shelf for example should not see the concept perspective of quality as either abstract or immaterial. This is because previous studies of Pringent-Simonin and Hérault-Fournier (21) and Becut (22) posited the concept perspective of quality as built up either by economic actors via voluntary agreements (product specification), or through public policy decisions (e.g., minimum quality standards). Becut (22) equally understood "quality" (applicable to agrofood products) could help to increase the competitiveness between items within a given market space. From another perspective also, the concept of quality can be either developed or initiated, based on cultural (signs and symbols associated with specific values associated with a specific items/products), legal (precise norms for intellectual property rights), and political (institutions that manage the certification, protection, and registration systems) platforms (22). In some of its clusters of interpretation, the concept of quality can be interchanged with "local" or "producer" who can be seen as responsible to impart some virtues to the given (agrofood) product. This will help consumers to socially perceive the concept perspective of quality, such that in this way, values like "authentic," "healthy," and "traditional" could then be associated with the given (agrofood) product (23).

Content Perspective of Quality

"Content" can be defined simply as everything that is contained in something (14). In line with this, the content perspective of quality would, therefore, consider the entirety of the information that can be deduced about the given agrofood product. Basically, agrofood products constitute nutrients. In fact, information about its quality is underpinned within its nutritional content. Considering the work of van der Spiegel (24), the content perspective of quality should corroborate well with the physical aspects of (agrofood) product quality, which can be measured, and demonstrated by composition, for example, the content of water. The content perspective of quality can therefore equally serve as a useful candidate to validate the consistency of performance variables of a given agrofood product.

Basically, carbohydrates, proteins, fats and oils, vitamins, minerals, and water constitute the nutritional composition of agrofood products. Considering the content of quality has been associated with the nutritional composition of agrofood products, consumers continue to depend on it taking into account all available/relevant information (25). Through the nutritional constituents, the content perspective of quality plays an important role, especially in the (nutritional) profile of a given agrofood product, which can be classified by food categories/subcategories, the latter largely depends on the profile's (nutritional) ratio (26). Nutritional profiles, in general, would likely have played a key role in developing, for example, the Healthy Eating Index, which measures the diet quality used to assess how well a set of foods associated with key recommendations of Dietary Guidelines for Americans (27, 28).

Another aspect to consider is when consumers look at any given packaged product on a supermarket shelf. Not only would they look at the nutritional contents, but they also look at the labels. Indeed, the content perspective of quality would equally be contributing to developing/establishing (shelf) labels, which allows for dates to get marked, especially in packaged agrofood products. For instance, the expiry dates explain the minimum durability date and can appear in two ways: (1) use up to/use by, or (2) better to use before/best before. Notably, some agrofood products can be exempt from expiry date markings, for example, bakery products (consumed usually 24 h post-production), beverages, chewing gum, cooking salt, synthetic vinegar, sugar, and wines (29).

Context Perspective of Quality

"Context" can be defined simply as the influences as well as events that explain or can be related to a particular situation (18). Looking at a given agrofood product, context perspectives can, therefore, refer to how one or more events/situations can influence the (product's) overall quality. In his well-cited text about planning for quality, Juran (30) argued that the defect-free characteristics exhibited in a given product can help avoid consumer dissatisfaction. Considering this, the "context" perspectives of quality might be instrumental in creating an understanding that connects the (agrofood) product performance with the degree of consumer satisfaction. Moreover, from the context standpoint, Fellows et al. (31) understood "quality" to depict the meeting up with a laid-down set of criteria, expectations, and specifications either agreed upon or well-established by the consumer toward a given (agrofood) product. In addition, the context of quality can, therefore, provide both consumers and sellers some form of choice to help them determine how quality is either embraced, interpreted, perceived, and or seen.

Previous workers such as van Rijswijk and Frewer (32) and Pinna et al. (33) associated quality, with such terms as "good product," "natural/organic," and "freshness," equally applicable to a given agrofood product. This would suggest that the context of quality has the capacity to help create some kind of descriptors for a given agrofood product. Moreover, Ilbery and Kneafsey (34) specifically linked the quality of the product (and services) to specific regions. Possibly, the context perspective of quality can help identify with the location(s) from which an agrofood product has either emerged from or been prepared. Consider a broad market scenario, it can be that the context perspective of quality may allow for product differentiation to take place in response to its demand (35, 36), which is equally applicable to agrofood products. If the context perspective of quality is to be looked at in a broader scope for agrofood products, it might actually help in understanding how and why several regulatory frameworks/standards develop and thrive across geographical continents/regions. For instance, the European Commission has adopted several regulations on the application of EU quality schemes. Take, for example, the legislation that explains the use of logos, how it is related to each quality scheme, and how such schemes should be approved, which covers the guidelines labels for agrofood products (37). In addition, labeling helps, not only in elevating the quality but also helps in enforcing it (38, 39).

REFLECTIONS ON SOME CONSUMER DECISION-MAKING-PURCHASE SCENARIOS

Consumers, in the selection of a given agrofood product, are confronted with decision-making processes made in varying time periods, particularly with respect to quality. The set of characteristics/properties that makes up a given agrofood product, in our opinion, can be seen as the foundation, which contributes to define as well as establish the quality of any given agrofood product, even at the time of purchase. Our opinion would agree with Manole et al. (4) who reiterated that quality has the capacity to represent a set of characteristics of, for example, a given agrofood product, which has the overall aim to meet up with consumers' needs. In addition, consumer, institution, and producer scenarios according to Ilbery and Kneafsey (11) can contribute to better the understanding of the quality of a given agrofood product. Therefore, to discuss these three facets of concept, content, and context perspectives of quality (of agrofood product) therefore comes very timely, considering the key role quality plays to the overall food supply chain/market, worldwide (40, 41). In addition, to implement the concept, content, and context perspectives of quality requires consumers to ascribe a certain degree of trust to the given agrofood product. Trust can be generalized (developed without intention), systematic (formalized in the laws/rules, based on institutional power), process based (repeated interactions between individuals/organizations), and personality-based (personal characterization of the individual) (42).

Most, if not all consumers, in making a decision during the purchase of a given agrofood product, are likely to consider at least two if not all of either concept, content, and or context perspectives of quality. Some consumers, depending on their (food quality) knowledge level, may likely possess some awareness, for example, nutritional specifics associated with the given agrofood product. Indeed, consumers might acquire some knowledge through their food-related experiences/exposures (14), which would guide/help them through the decision-making process, either at the point or period of purchase. Similarly, consumers considering buying either fresh fruits and or vegetables in a food retail store, for example, could apply their personal instincts to help them choose/differentiate between one product over the other, and at the same time, considering their perceived concept, content, and context perspectives of quality. For example, customers at the fishmongers/meat butcher's shop(s), in this instance, could make the effective use of their personal instincts to perceive/view concept, content, and context perspectives of quality.

A consumer preference if consistent to a specific agrofood product over another competing one shows a strong agreement with the (specific product) performance. This could be a

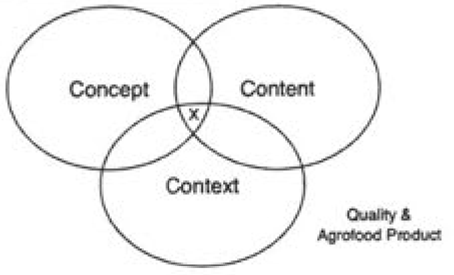

FIGURE 1 | A diagrammatic representation of interaction space between concept, content, and context perspectives of quality of a given agrofood product. The interaction between the three, indicated with "X," that is, concept vs. content vs. context perspectives of quality.

reflection on how that specific consumer might have embraced, interpreted, and perceived (31) the quality of that specific agrofood product. Many consumers, in reality, are likely to take some time to check the (agro)food package labels, product (nutritional) content as well as date markings in the process of purchase. Some scenarios may well take place where a consumer who does not usually check these, is being accompanied by another who possess better/increased knowledge about that given specific agrofood product. Sharing knowledge is able to strengthen the other's decision-making. Whether the decision-making to purchase a given agrofood product is self, or influenced by another, there would always be some interaction between concept, content, or context perspectives of quality. Another instance is that perspectives of quality could have some influence based on where the agrofood product is made/prepared and the success of its sales. An example that can fit well is pizza. It is now so diverse and found in many parts of Europe. Pizza makers largely adjust and modify the emergent/resultant product quality to suit the traditional choices of the target locality/population so as to achieve optimum sales. The same pizza from one maker will likely differ from another on the same street! Consumers at the purchase of pizza effectively interact with the concept, content, and context perspectives of quality. Most likely, consumers' experience after consumption will either persuade or dissuade their return to the same pizza shop. In order to meet consumer expectations (31), pizza makers have to establish their product quality (as well as service to that specific region) (34), which increases the product competitiveness at the market place (22).

A diagrammatic representation of interaction space between concept, content, and context perspectives of quality of agrofood product is shown in **Figure 1**. There appears a thin line that would separate concept, content, and context perspectives of quality in the choice/decision-making of agrofood products. Specifically, solely depending on either concept, content, or context perspective will provide the consumer with insufficient and limited information about the quality of the given agrofood product, in order to make the appropriate decision on whether or not to purchase. An interaction between any two, which could be either, concept vs. content, concept vs. context, or content vs. context perspectives will most likely improve information about the quality of the given agrofood product. Obviously, the interaction between the three, indicated with "X" in **Figure 1**, that is, concept, content, and context perspectives of quality, would most likely provide sufficient information about the quality and help consumer make a more informed decision of purchase. As a result, the consumer's participation in the decision-making process of purchase will be strengthened, which would help achieve the desired as well as preferred choice of an agrofood product, to help meet up with (specific) demands/needs. In addition, consumers may not realize when concept and content, concept and context, and or content and context perspectives of quality might have actually interacted, particularly in their decision-making process to purchase a given agrofood product.

CONCLUDING REMARKS

Concept, content, and content perspectives of quality are very relevant to any given agrofood product. There appears a thin line that would separate concept (principle or idea about something), content (everything contained in something), and context (influence and events related to a situation) perspectives of quality in the choice/decision-making of agrofood products. In the view to enhance the choice and decision-making of a given agrofood product, there should always be some interaction between concept, content, and context perspectives. Considering that decision-making is one of the factors influencing consumer preference to quality, other factors for future works need considerations, including price, economic status of buyers, season, media, advertisement, availability, etc. Future works reflecting on how these other factors connect with consumers' concept, content, and context perspectives of quality of agrofood products are required, which can help in delineating more pieces of information influencing the choice/decision-making processes of quality of agrofood products, so as to make them more appropriate at the time of purchase.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The idea was conceived and developed by CORO, who prepared the initial draft. MK corrected and edited the article. All the involved authors approved the final manuscript.

FUNDING

Publication financed by the project UPWR 2.0:international and interdisciplinary programme of development of Wrocław University of Environmental and Life Sciences, co-financed by the European Social Fund under the Operational Program Knowledge Education Development, under contract No. POWR.03.05.00-00-Z062/18 of June 4, 2019.

REFERENCES

1. Williams SC. Perceptions of quality in the Queensland seafood industry. *Asia Pac J Qual Manag.* (1993) 2:46–58.
2. Juran JM. *Juran on Leadership for Quality: An Executive Handbook.* New York, NY: The Free Press-Coller-Macmillan (1989). pp. 376.
3. Bremner HA. Toward practical definitions of quality for food science. *Crit Rev Food Sci Nutr.* (2000) 40:83–90. doi: 10.1080/10408690091189284
4. Manole V, Stoian M, Ion R. *Agricultural Marketing.* Bucharest: ASE Publishing House (2001).
5. Holleran E, Bredahl ME, Zaibet L. Private incentives for adopting food safety and quality assurance. *Food Policy.* (1999) 24:669–83. doi: 10.1016/S0306-9192(99)00071-8
6. Trienekens JH, Zuurbier PJ (Eds). *Proceedings of the 2nd International Conference on Chain Management in Agri- and Food Business. Ede, May 30-31, 1996.* Wageningen: Department of Management Studies, Wageningen Agricultural University (1996). pp. 632.
7. Oziebłowski M, Lesiów T, Szkudlarek S, Korzeniowska M, Bobak L, Szmańko T. Objective and subjective estimation of colour in predicting the quality of breast chicken muscles. *Zeszyty Naukowe Uniwersytet Ekonomiczny Poznaniu.* (2010) 158:104–14.
8. Banks J, Bristow G. Developing quality in agro-food supply chains: a Welsh perspective. *Int Plann Stud.* (1999) 4:317–31. doi: 10.1080/13563479908721745
9. Gheorghe I. Analysis of Agro-food Products' Quality. *Competitiveness of Agro-Food and Environmental Economy, 229, CAFEE'12 Bucharest Conference, 8-9 November* (2012).
10. Goodman D. The quality turn and alternative food practices: reflections and Agenda. *J Rural Stud.* Bucharest: Faculty of Agro-Food and Environmental Economics, Bucharest University of Economic Studies (2003) 19:1–7. doi: 10.1016/S0743-0167(02)00043-8
11. Ilbery B, Kneafsey M. Producer constructions of quality in regional speciality food production: a case study from south west England. *J Rural Stud.* (2000) 16:217–30. doi: 10.1016/S0743-0167(99)00041-8
12. López XA, Martin BG. Tourism and quality agro-food products: an opportunity for the spanish countryside. *Tijdschrift Econ Soc Geografie.* (2006) 97:166–77. doi: 10.1111/j.1467-9663.2006.00510.x
13. Morris C, Young C. 'Seed to shelf', 'teat to table', 'barley to beer' 'womb to tomb': discourses of food quality quality assurance schemes in the UK. *J Rural Studies.* (2000) 16:103–15. doi: 10.1016/S0743-0167(99)00044-3
14. Dequiedt V. *Product Quality in Developing Countries Agrifood Supply Chains: A Survey of Theory.* Universite Clermont Auvergne, CNRS, IRD, CERDI, France, pp. 19, November (2018). Available online at: https://ferdi.fr/dl/df-r5s6cxeybQjy546NQfyLoL7t/papier-de-recherche-product-quality-in-developing-countries-agrifood-supply.pdf (Accessed September 1, 2020).
15. Viscusi WK. A note on lemons markets with quality certification. *Bell J Econ.* (1978) 9:77–9. doi: 10.2307/3003627
16. Tsiros M, Heilman CM. The effect of expiration dates and perceived risk on purchasing behaviour in grocery store perishable categories. *J Market.* (2005) 69:114–29. doi: 10.1509/jmkg.69.2.114.60762
17. Newsome R, Balestrini CG, Baum MD, Corby J, Fisher W, Goodburn K, et al. Applications and perceptions of date labeling of food. *Compr Rev Food Sci Food Saf.* (2014) 13:745–69. doi: 10.1111/1541-4337.12086
18. Cambridge Dictionary. Available online at: http://dictionary.cambridge.org/dictionary/english (accessed January 14, 2020).
19. Ahaus CTB, de Heer A, Vos AMAM. *'Kwaliteitskosten, wat baat het?: ervaringen met' Kwaliteitsevaluatie-KKO.* Nederlands: Kluwer Technische Boeken (1988). p. 148.
20. Mogezomp HG, Diependaal MJ, Leroy P. Het milieu-kwaliteits-kosten-model. Milieu (1992). p. 13–8.
21. Pringent-Simonin A-H, Hérault-Fournier C. The role of trust in the perception of the quality of local food products: with particular reference to direct relationships between producer and consumer. *Anthropol Food.* (2005) 4. doi: 10.4000/aof.204
22. Becut A. Apples, quality signs and trademarks for local products. *Int Rev Soc Res.* (2011) 1:65–83. doi: 10.1515/irsr-2011-0011
23. Anthopoulou T. Rural women in local agrofood production: Between entrepreneurial initiatives and family strategies. A case study in Greece. *J Rural Stud.* (2010). 26:394–403. doi: 10.1016/j.jrurstud.2010.03.004
24. Van der Spiegel M. *Measuring Effectiveness of Food Quality Management.* Doctoral Thesis at Wageningen Universiteit (2004). 192 p.
25. Marette S, Nabec L, Durieux F. Improving nutritional quality of consumers' food purchases with traffic-lights labels: an experimental analysis. *J Cons Policy.* (2019) 42:377–95. doi: 10.1007/s10603-019-09420-5
26. Nasreddine L, Taktouk M, Dabbous M, Melki J. The extent, nature, and nutritional quality of foods advertised to children in Lebanon: the first study to use the WHO nutrient profile model for the Eastern Mediterranean Region. *Food Nutr Res.* (2019) 63:1604. doi: 10.29219/fnr.v63.1604
27. French SA, Tangney CC, Crane MM, Wang Y, Appelhans BM. Nutrition quality of food purchases varies by household income: the SHoPPER study. *BMC Public Health.* (2019) 19:231. doi: 10.1186/s12889-019-6546-2
28. Guenther PM, Kirkpatrick SI, Reedy J, Krebs-Smith SM, Buckman DW, Dodd KW, et al. The healthy eating index-2010 is a valid and reliable measure of diet quality according to the 2010. Dietary Guidelines for Americans. *J Nutr.* (2014) 144:399–407. doi: 10.3945/jn.113.183079
29. State of Israel: Ministry of Health 'Food Label and Nutritional Labeling'. Available online at: https://www.health.gov.il/English/Topics/FoodAndNutrition/Nutrition/Adequate_nutrition/Pages/labeling.aspx (accessed January 14, 2020).
30. Juran JM. *Juran on Planning for Quality.* New York, NY: The Free Press (1988). 341 p.
31. Fellows P, Axtell B, Dillon M. *Quality Assurance for Small-Scale Rural Food Industries.* FAO Agricultural Services Bulletin, 117. FAO-Rome (1993).
32. Van Rijswijk W, Frewer LJ. Consumer perceptions of food quality and safety and their relation to traceability. *Br Food J.* (2008) 110:1034–46. doi: 10.1108/00070700810906642
33. Pinna M, Velčovska S, del Chiappa G. The food quality labels: awareness and willingness to pay in the context of Italy. *Proceedings from the XII International Conference Marketing Trends, Paris-Venice: Paris-Marketing Association.* (2014). Available online at: http://archives.marketing-trends-congress.com/2014/pages/PDF/298.pdf (accessed January 14, 2020).
34. Ilbery B, Kneafsey M. Product and place: promoting quality products and services in the lagging rural regions of the European Union. *Eur Urban Region Stud.* (1998) 5:329–41. doi: 10.1177/096977649800500404
35. Renard M-C. Quality certification, regulation and power in fair trade. *J Rural Stud.* (2005) 21:419–31. doi: 10.1016/j.jrurstud.2005.09.002
36. Valceschini E, Nicolas F. *Agro-alimentaire: Une Économie de la Qualité.* INRA Economica, Editions Quae (1995). 433 p.
37. Agriculture and Rural Development, Regulations on Food and Agricultural Products (Law): European Commission. Available online at: http://ec.europa.eu/info/publications/regulations-food-and-agricultural-products_en (accessed January 14, 2020).
38. Furquim de Azevedo P, dos Santos Silva VL. Food franchising and backward coordination: an empirical analysis of Brazilian firms. *J Chain Netw Sci.* (2003) 3:33–44. doi: 10.3920/JCNS2003.x028
39. Fernandez Barcala M, Gonzales Dias M, Arrunada B. Quality Assurance Mechanisms in the Agrofood Sector: The Meat Sector Case In: *Paper presented in the 5th Annual Conference of the International Society for New Institutional Economics.* Available online at: http://www.isnie.org/ISNIE01/Paper01/barcala-diaz-sanchez.pdf/ (accessed August 11, 2020).
40. Umali-Deininger D, Sur M. Food safety in a globalizing world: opportunities and challenges for India. *Agric Econ J Int Assoc Agric Econ.* (2007) 37:135–47. doi: 10.1111/j.1574-0862.2007.00240.x
41. Chen C, Zhang J, Delaurentis T. Quality control in food supply chain management: an analytical model and case study of adulterated milk incident in China. *Int J Prod Econ.* (2014) 152:188–99. doi: 10.1016/j.ijpe.2013.12.016
42. Franz M, Rolfsmeier S. Brands, trust, and quality, in agrofood production networks: the case of layer hens. *Geografiska Ann Ser B.* (2016) 98:271–86. doi: 10.1111/geob.12103

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

04 czerwca 2023 r

(miejscowość i data)

...Charles Odilichukwu R. OKPALA...
Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych
Wydział Biotechnologii i Nauk o Żywności
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy ...... *Okpala, C. O. R., & Korzeniowska, M. (2020). Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. Frontiers in Nutrition, 7, 578941.*... mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

Okpala

04 June 2023..............
data i podpis

dr hab Małgorzata Korzeniowska, prof. uczelni

03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., & Korzeniowska, M. (2020). Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. Frontiers in Nutrition, 7, 578941,* mój udział polegał na konceptualizacji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

FOOD REVIEWS INTERNATIONAL
2023, VOL. 39, NO. 4, 1879–1952
https://doi.org/10.1080/87559129.2021.1938600

Taylor & Francis
Taylor & Francis Group

REVIEW

OPEN ACCESS Check for updates

Understanding the Relevance of Quality Management in Agro-food Product Industry: From Ethical Considerations to Assuring Food Hygiene Quality Safety Standards and Its Associated Processes

Charles Odilichukwu R. Okpala and Małgorzata Korzeniowska

Department of Functional Food Products Development, Faculty of Biotechnology and Food Sciences, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

ABSTRACT
The continuous improvement in good practices and implementation of hazard analysis and critical control points (HACCP) remains very crucial for food hygiene quality safety to steadily thrive in the agro-food product industry sector. To improve the agro-food product quality, the dependency of quality management (QM) on such key facets as quality assurance (QA), control, improvement, and planning appears to be on the rise. Herein, how food hygiene quality safety standards and their associated processes have been assured is described. To understand the relevance of QM in the (above-mentioned) processes, we discuss some ethical quality considerations, food quality safety standards, HACCP fundamentals/implementation, QA control systems, other quality standards associated with agro-food industry, together with supplementary essentials associated with quality. Through the combined efforts of HACCP and QA control points (QACP) such as improved food hygiene, both quality, and safety levels can be further enhanced and sustained. Establishing the QM system within a given agro-food product enterprise is not the real deal, what matters most is how to maintain and sustain it. Some challenges encountered during the auditing/implementation processes of food safety management systems, as well as directions for future studies, involving QM, QA, and food hygiene quality safety, are presented.

KEYWORDS
Agrofood industry; quality management; food safety; food quality; product quality; quality improvement

Introduction

Quality management (QM): Some basic links to agro-food product industry

Quality management (QM), strategically integrated into operations of many companies, has been largely based on mutual yet reinforcing principles, which are supported by a set of practices.[1,2] Key in determining the quality objectives, policy, and responsibilities at a wide range of sectors, QM remains implemented through quality assurance (QA), control, improvement and planning, providing unlimited emphasis to practice, especially if the primary objective of the organisation (or product quality) achievement were to be consistent.[3,4] For the QM to be effective, therefore, it has to utilise components like continuous improvement/learning, customer focus and orientation, empowerment and teamwork, human resource focus, quality tools, robust management structure, strategic planning/leadership and supplier support.[5–7] Each QM expert has to possess the prerequisite 'key practices', which remain fundamental not only for the attainment of the superior quality outcomes,[8] but also for the realisation of the (robust) organisational improvements.[1] In addition, the quality definitions

CONTACT Charles Odilichukwu R. Okpala charlesokpala@gmail.com

This article has been republished with minor changes. These changes do not impact the academic content of the article.

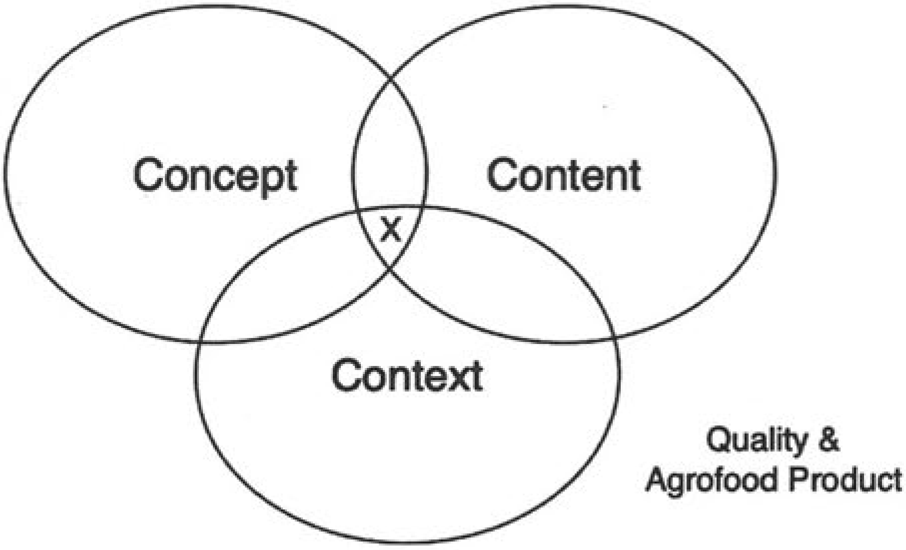

Figure 1. A diagrammatic representation of the interaction space between concept, content and context perspectives of quality of a given agro-food product. The interaction between the three, indicated with "X", that is, concept versus content versus context perspectives of quality (Source: Okpala & Korzeniowska [15]).

facilitate both the implementation processes and the working of performance-based parameters, which arise from the quantification of delivery of values to the consumers/stakeholders. [9] Previous studies about QM practice have involved employees' empowerment/relationship, employees' training/learning, [10–13] supplier closeness and relationship, [10,12–14] as well as QM's link to the customers' closeness/focus.[10,12,14]

Quality should neither be perceived as a scientific or technical word, nor as physical entity with a fixed position in space and time. It should be considered an essential aspect of any existing economic activity, with direct impact on consumer, producer, as well as product and service.[15] Indeed, quality attributes in agro-food products remain somewhat difficult to identify and observe. Quality attributes specific to one product stands it unique compared to the other, which underscores that there are concept, content, and context perspectives of quality.[15] A diagrammatic representation of the interaction space between concept, content and context perspectives of quality of a given agro-food product is shown in Fig. 1. We understood that there is likely to be a thin line that would separate concept, content and context perspectives of quality, especially when it involves the choice/decision-making of purchase of agro-food products. On the other hand, and also specific to the agro-food product industry, quality would involve a wide range of ideas, from the aesthetic standard for product set by experienced users, the extent to which a product fulfils the consumer needs/wants, conformance to requirements, degree of excellence (of a food product), and summation of attributes that govern food product acceptability to buyer/consumer.[16] The quality systems can also comprise management structures, infrastructures, product characteristics followed by the production processes.[17] Therefore, making QM complete demands quality practice geared towards attaining world-class quality.[18] The prospect of individuals to compete via QM initiatives is also relevant to agro-food product industry. Some firms sometimes do not actualise this, making such unable to compete effectively within the (national/global) market.[7]

Some highlights about food safety in the agro-food product supply chain

From the preservation, processing, production, and storage standpoints, to sustain global food systems would involve such elements as climate, available land space, and technology. Despite the focus to have effective quality control at all the stages of the food supply chain,[19] there are some notable challenges that confront the food sector can include a) highly perishable food products; b) manual/very limited

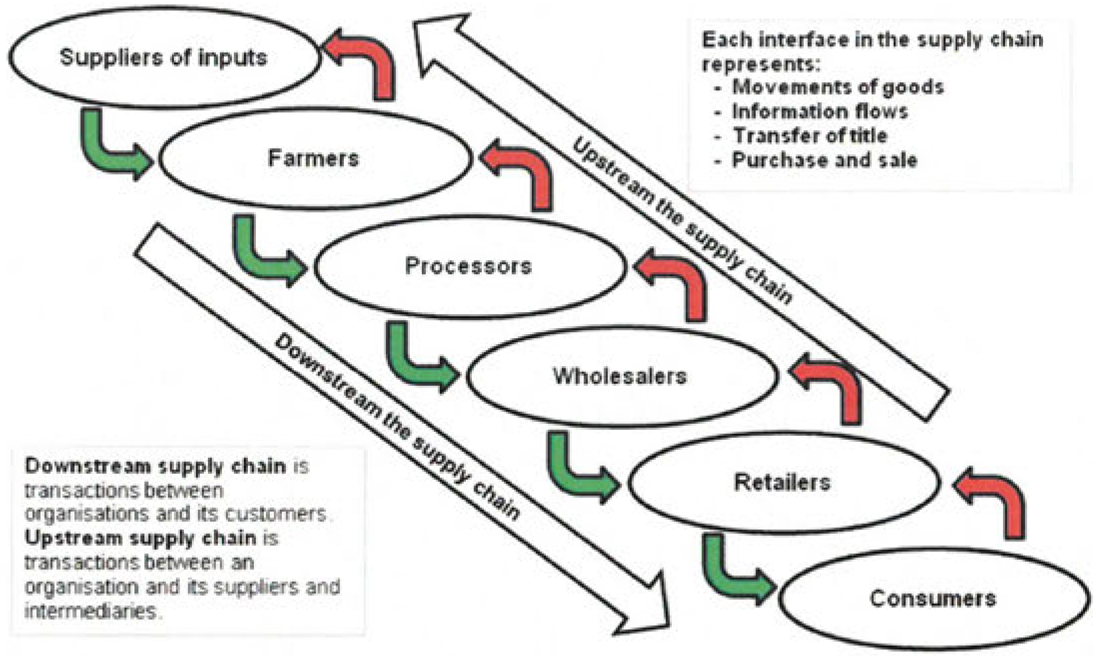

Figure 2. A diagrammatic representation of a typical agro-food product supply chain. From the consumers to the suppliers, the downstream (green) and upstream (red) direction flow of transactions takes place within the supply chain (Source: Costa-Font & Revoredo-Giha.[21])

automatic operation(s); c) variations in the quality of raw materials; d) augmented dissimilarities of composition/products; e) processing techniques; and f) reduced volume of batches.[20] A diagrammatic representation of a typical agro-food product supply chain can be seen in Fig. 2. The direction of downstream and upstream aspects of the food supply chain can be seen to interconnect with the interface transaction(s), which is represented by the flow of information, movement of goods, purchase, and sale as well as the transfer of title(s).[21] As the food industry continually searches for more innovative production strategies, there is a need for efforts to persist in the areas of consumer protection and food preservation.[22] Despite being responsible for delivering an objective as well as a transparent food safety plan, the agro-food product industry must ensure that the hazard measures are in place for (product) safety.[23] The affordability of applying/introducing food safety instrument determines the degree of progress of the local (food) management strategies.[23] Notable factors that influence food quality/safety can include a) inadequate storage; b) inappropriate temperature levels; c) poor air quality; d) poor humidity; and e) poor lighting. In addition, farmers, suppliers, wholesalers, retailers as well as transporters are obliged to sustain the conditions of food products' quality and safety.[24]

Globally, many countries are prioritising to improve food control systems by the way of food laws as well as food hygiene regulations/standards. However, food quality/safety is still confronted with challenges, and some examples can include a) importation and exportation of food; b) street foods; c) food transportation; d) zoonotic pathogens; and e) chemical agents in foods.[25] From the global viewpoint, it can be said that the consumers' persistence for food safety has contributed in facilitating the food industries to vigorously pursue the implementation of various (food safety) standards, like British Retail Consortium (BRC), International Featured Standards (IFS), Hazard Analysis of Critical Control Points (HACCP) as well as ISO 22000:2005. Yet, not all the formal quality systems are welcomed by food industries.[26] Two major international organisations involved in the development of food quality safety systems include a) Food and Agricultural Organization (FAO); and b) World Health Organization (WHO), both largely collaborating through the Codex Alimentarius Commission, implementing the joint FAO/WHO Food Standards Programme. Of lesser extent, however, the International Commission on Microbiological Specification for Foods (ICMSF), United Nations Industrial Development Organization (UNIDO), General Agreement on Tariffs and Trade (GATT), International Standard Organization (ISO), International Organization of Consumer Union (IOCU) and International Dairy Federation (IDF) have been understood to participate in the international food quality safety control.[27]

As good practices contribute to protect the production process within the agro-food industry/sector, the QA plays a vital role to make the operational activities work effectively and efficiently. Depending on the purpose, the focus of good practices can be of private or public aspects, despite the complexities associated with the food supply chain.[28] Hazard analysis and critical control point (HACCP), already acknowledged by the FAO+WHO, European Commission (EC) as well as Australian and New Zealand Food Authority, is increasingly becoming popular in the developing countries, as a means of assuring the food quality safety.[29] In addition, HACCP is also very relevant to religious food safety.[30] In the situation of export and across trade barrier(s), food safety standards have challenges, like a) delicate nature of fresh food product regional trade; b) role of farm-to-table approaches that assure safety; c) the role of the public sector between nations to facilitate trade; and d) potential role of nations based on the agreement to resolve disputes and determine equivalencies of standards.[23] In the European market also, food quality standards remain critical in meeting consumers'/regulatory bodies' requirements.[31]

Justification and specific objective of review

Shelf life concerns are among key issues that continually pose a wide range of challenges to the food product supply chain, from product development, processing, to the distribution as well as storage stages [32]. Further, the food product quality safety would continue to require (product) stability in order to fulfill basic and fundamental consumer expectations.[33] Previous published synthesised literature reviews, from good practices, quality assurance/management systems, to related aspects relevant to the agro-food product industry conducted in the course of the past two decades by several researchers, is summarised in Table 1. Largely, the current state-of-the-art has focused on areas like auditing, food safety, food quality standards in the food industry,[26] good practices for fresh (agro-food) produce/total chain safety,[34,42] food safety management system,[37,39] HACCP certification with the quality standard,[49,51] as well as understanding the food quality, entities, and systems.[46] Applicable to the agro-food product industry, there are areas like quality assurance,[38,44,45,47] quality function deployment,[50] quality management[20,36] and quality safety standards/systems[40,43] that have been previously reported. Reviews concerning food quality that are connected to waste[35] and organisational issues in providing safe wholesome food[48] can also be seen in Table 1.

Despite the above-mentioned previously conducted reviews, the current status of QM in connection with food hygiene quality safety standards within the agro-food product industry, in our opinion, appears not fully established. According to Okpala et al. [52] the continuous assembly/synthesis of relevant reviews together with contextualisation and quantification of published data is necessary if the existing information is to be supplemented. Thus, understanding the current status of QM, particularly on how it drives the progress of good practices within the agro-food product industry should be a useful start. Besides, the food industry continually seeks to increase the food product quality and consumer protection/safety through the practice of quality assurance, good (hygiene food safety quality) practices/processes, legislative and regulatory standards, and other quality-related processes. In this current review, how food hygiene quality safety standards and its associated processes have been assured is described. In order to understand the relevance of QM in the (above-mentioned) processes, some ethical quality considerations, food quality safety standards, HACCP fundamentals/implementation, QA control systems, other quality standards associated with the agro-food industry together with supplementary essentials associated with quality will be discussed. In addition, some challenges encountered during the auditing/ implementation processes of food safety management systems, as well as directions for future studies, involving QM, QA, and food hygiene quality safety, will be presented.

Table 1: Summary of previous published synthesized literature, from good practices, quality assurance/management systems, to related aspects relevant to agro-food product industry

References	Objective/purpose of review	Major sections covered
Kotsanopoulos and Arvanitoyannis [26]	Examined the role of audits and food safety and quality assessment systems in the food industry, with brief description about global food safety and quality standards	-History of Auditing; -The Auditing Process; -The Role of Safety and Quality Control Systems; -The Role of Governments; -Food Safety and Quality Standards; -Auditing Authorities in Europe, U.S., Autralia and New Zealand; -Implementation of Food Safety Standards in Asia and Food Safety Authorities
Wongsprawmas, Canavari, and Waisarayutt [34]	To describe and analyze current situation of good agricultural practices (GAP) standards implemented in fresh (agro-food) produce production in Thailand	- Law and regulations regarding to food safety in Thai food production industry; - GAP scheme adoption in Thai fresh produce production; -Comparisons of GAP standards; and - Challenges in adopting food safety assurance system in Thai fresh produce production.
Śmiechowska and Kłobukowski [35]	To evaluate current knowledge of issue of food quality in connection with waste, its importance for natural environment, state budget and home dwellings	-The notion of quality; -The cause of food waste; and -Ways to counteract food waste.
Kibe and Wanjau [36]	Explores quality management systems and their influence on performance of food processing firms in Kenya	-Food safety assurance systems; -Hazard analysis critical control points (HACCP); -Seven principles of HACCP; -HACCP plan; -Organizational Procedure; -Conceptual framework; and -Critical review
Dora, Kumar, Goubergen, et al. [20]	To review assessment strategies of food quality management system using a feasibility study for EU small-medium sized (food) enterprises	-Introduction of literature of quality and quality management implementation; -Summary of methodology employed to conduct the review; -Results of feasibility study was presented; -Benefits of and barriers to food industry; and -Limitations of study presented, followed by conclusions and future research.
Jacxsens, Luning, Marcelis, van Boekel et al. [37]	To review principles and usefulness of various tools developed in EU to support food business operators in enhancing their food safety management systems (FSMS)	-Process of performance assessment, selection and improvement of food safety management systems; -Diagnostic tools; -Selection tools; -Improvement tools; and -FMSM support systems
Karipidis, Athanassiadis, Aggelopoulos, and Giompliakis [38]	To pinpoint factors that affect decision of small enterprises to adopt quality assurance system (QAS) with the intent of facilitating its rapid diffusion in European small food enterprises	-Benefits/advantages implementation of QAS; -Barriers to implementation of QAS; and -QAS diffusion policy
Luning, Marcelis, Rovira, van der Spiegel, Uyttendaele, et al.. [39]	To discuss core assurance activities, its contributions to assurance and how to judge activities in a company's food safety management system (FSMS)	-Food safety management system; -Structure diagnostic instrument; -Core assurance activities; -Assessment of assurance activities; and -Usefulness of diagnostic instrument and future perspectives
Trienekens and Zuurbier [40]	To review quality and safety standards in the food industry, developments and challenges	-Need for food safety standards; -Quality and safety characteristics of food production; -Food quality standards; -Implementation and impact
Raspor and Jevšnik [41]	Analyses good practices at different levels of food production, distribution and consumption	-Good practices from producers to consumers; -Food safety parameters; -Food safety dilemma of consumer; -Good nutritional practice from producer to consumers

(*Continued*)

Table 1 (Continued).

References	Objective/purpose of review	Major sections covered
Raspor [42]	To demonstrate how good practices can contribute to the attainment of total food chain safety	-Background and how to reach acceptable food safety; -Consumer-neglected link in the food chain; -New food safety concept; and -Future outlooks
Knaflewska and Pospiech [43]	To outline appropriate standards and systems functioning in food industry as well as legal basis for their application	-Safefood and legal basis; -Traceability in practice; Systems of food quality
Da Cruz, Cenci and Maia [44]	To present information about main factors responsible for the elaboration of quality assurance system for produce plants of food industry	-Quality assurance; -Good agricultural practices (GAP); -Good manufacturing practices (GMP); -Sanitation standard operating procedures (SSOP); -Hazard analysis critical control points (HACCP);and -Future prospects
Manning, Baines, and Chadd.[45]	To critically analyze how effectively quality assurance (QA) standards has been implemented in the integrated UK food supply chain	-QA schemes; -Organizational/supply chain QA models; -Current QA models; and -Benchmarking within food supply chains
Doyon and Lagimonière [46]	To focus a better understanding and defining food quality, entities and system component	-Briefs about quality assurance, GMP, HACCP, Food safety, audit, risks and certification; -Risk analysis tools for quality management are traceability system; and -Traceability tools and definition, concept, principles and guidelines/standards
Sikora and Strada [47]	An overview of safety and quality assurance and management systems in food industry	-Food quality and safety; -Quality assurance and management systems; and - Making quality management systems work
Manning and Baines [48]	To identify organizational issues if management systems primarily focused on minimizing quality cost rather than providing safe wholesome food	-Private assurance schemes; - Why quality assurance; -Criteria for certification bodies; -Regulatory inspection vs quality assurance schemes; -Whole supply chain assurance; - Hazard analysis critical control points (HACCP); and -Risk management and impact of food globalization
Jatib [49]	To comparatively analyze HACCP, Quality and Origin Protocol, and ISO9001 Quality Management affecting agribusinesses in Argentina	-Food safety self control program; -Green Beef Protocol – Self Certification Model; and - Implementation of Strategic Plan and ISO9001
Costa, Dekker and Jongen [50]	To review the application of quality function deployment (QFD) in the food industry	- QFD implementation; -QFD in food industry; - Benefits and drawbacks of QFD for food research and development (R&D); -Challenges remaining for QFD practitioners in food R&D.
Caswell, Bredahl and Hooker [3]	How adoption of new quality management metasystems affects specifics of food systems and how these effects might be quantified	-Why adopt 'metasystem'?; -Internal benefits and costs of metasystems; -Transaction costs and system efficiencies; -Developing a competitive advantage; -Interactions among metasystems; -HACCP as a mandatory quality control metasystems; -ISO9000 series as a voluntary quality control metasystem; -Quasi-voluntary metasystem: How free a choice? and -How can the effects of metasystem be evaluated?
Barendsz [51]	To review developments in HACCP certification, the standardisation of risk assessment, the necessity of chain formation in the agro-food sector and the improvement of global communication	-HACCP as part of total quality management system; -HACCP certification; -Risk assessment; -agro-food chains; and -Global communication

Some ethical quality considerations applicable to agro-food product industry

It is believed that QM emerged because factory management over time was found in desperate need for quality manager functions, which would strategically balance the authority of the production managers. Indeed, this approach has helped to address several quality concerns, which at the end was found to strengthen the control systems within acceptable (quality-driven) standards.[53] Markkula Center of Applied Ethics at Santa Clara University considered ethics as well-founded standards of right and wrong, which prescribes what humans ought to do, based on benefits to society, fairness, obligations, rights, or specific virtues.[54] So, ethics would well apply to QM as it does to all aspects of human endeavours. Wicks[55] indicated that to implement QM requires the understanding of what makes it to work, and what circumstances provides it a sustainable advantage. Thus, there are moral values (also called 'value dynamics') that have to be developed if QM is to work.[4] In addition, Ahmed and Machold [56] understood that both ethics and morality could increase awareness about quality practice. In fact, both ethics and morality, if and when rigorously incorporated into an organization could play a strong role to improve the managerial (and operational) aspects of the QM experience. In addition, quality has a paradigm viewpoint that explicitly incorporates virtue, which cannot be successfully managed without moral values. Ethical behaviour would therefore assume complete control of quality to answer moral questions adequately,[57] which can apply to quality assurance/ management of the agro-food product industry.

Especially in the real-time scenario, the collective package of integrity-trust-virtue continually fails to stand significant and strong, especially in its meaning, regardless of the QM components. Therefore, if the ethical issues were to be considered particularly within the quality framework, the latter should be based on the belief in the goodness of people, as well as continuous quality improvement. Besides, the usefulness of ethics in QM should be made to involve an evidenced commitment to the ethical standards, together with virtue and integrity – an attitudinal and value-based method of achieving an increased level of quality practice.[56] Additionally, in order to realise ethical accountability, there are a number of useful elements that must be put in place, and some examples include benefits, care, equity, integrity, liberty, no-harm, transparency, and voice.[56] In addition, Barney and Hansen [58] understood that trustworthiness could serve as a key source of competitive advantage. Actually, there are three types of trust that have been established in the relevant literature, which include: weak, semi-strong, and strong. Further, Wicks [55] understood that cooperation and trust together could empower the management of a given organization so as to increase their productivity, which would result in the continuous (operational) improvement, customer satisfaction as well as short/long-term kind of advances/successes, particularly in the delivery of QM practice. Thus, the combined working of respect and trust in managing quality processes is very crucial and essential. Besides, that is why good positive supervision certainly motivates employees. Treating employees respectfully when there are under-taking meaningful duties in their workplace(s) promotes freedom as well as liberty, and should not be misused.[57,59,60] Behaviour, communication, considerations, and values of individuals are well known to strengthen the foundation for relational responsibility. Continually, effective and responsible control should persistently underpin the internal process, particularly when combined with personal care. Then, customers, employees, and society can strive for QM practice.[57–60] Indeed, all the above-mentioned ethical quality considerations apply well to the agro-food product establishment/industry.

Food safety knowledge – Some key fundamentals

Regardless of the location, to prepare food in the right hygienic standards, there has to be the appropriate knowledge that produces the effective food-handling skills. To achieve this, there has to be the right motivation to act on that knowledge. For emphasis, knowledge entails when factual information employed by a learner is utilised to perform a given task in the desired and specific manner.[61] However, to achieve the required level of food safety knowledge, there must be the education that is fortified with proven validity or reliability instruments.[62] Previous research has

Figure 3. Key direct and indirect components that influence food safety knowledge.

revealed that people have the capacity to increase their food safety knowledge with time and practice.[63] In particular, it is believed that females would have higher food safety knowledge scores compared with the males. In addition, the younger people are believed to demonstrate the greater need to undertake additional food safety education.[63–66] There is also the understanding that people from the urban are likely to have lower food safety knowledge scores compared with those from rural areas.[63,64]

Food safety knowledge comprises various components, which could deliver either direct or indirect influence, as depicted in Fig. 3. It will be remiss to discuss food safety knowledge without directly involving food handling, food safety systems, good practices, HACCP, food quality/standards, and indirectly involving food culture/traditions, and production/processing. Various studies that investigated food safety knowledge has involved one or more of the above mentioned. Indeed, accepting food safety systems has put employees' training under the critical observations.[67,68] In order to put food safety knowledge into action at any given food enterprise, the performance of the working procedures must operate at a high-quality level, which must adhere to the food hygiene with HACCP, and its associated principles. This has to be so, in order to assure efficiency in food safety, to prevent foodborne diseases,[68] which is also depicted in Fig. 3. If food safety knowledge is absent, or not deficient among food service workers, there is likelihood that the spread of foodborne outbreaks to become a reality.[69] Besides, there are common food handling errors that can occur, for example, allowing too much of a time lapse when cooling food, cooling food inappropriately, inadequate cooking, reheating of foods consumption of food obtained from unsafe sources.[62,70]

Despite the adherence to existing framework/standards, to implement/practice food safety knowledge remains very relative as it would differ from person to person, place to place, as well as scenario to scenario. Regards person-to-person, the food safety knowledge of food service personnel in a typical restaurant with diverse menus, would differ from food service personnel in, for instance, a given fish or meat shop. If food safety knowledge of consumers for example, specific to the status of kitchen components, were to be assessed, the outcomes would not be the same as food safety knowledge of food service providers in a restaurant. Moreover, there are numerous studies already conducted on food safety knowledge (and practices), and examples range from elderly people living at home,[71] consumers,[72,73] street food vendors in a given city,[74] food handlers,[68,75] to catering employees like head chefs, managers, [76,77] as well as students in tertiary institutions.[78–80]

Food quality safety standards – a primer

Food safety standard captures a wide range of items, from hygiene standards of food packaging materials, labelling standards of food labels, agricultural production environment, to harmful microorganisms and pollutants in foods.[81] Food quality/safety standard has always been underpinned by the work of the Codex Alimentarius Commission (CAC), which has been positioned as the global policy reference point for the food producers, processors, consumers, as well as the national food safety agencies. Both FAO and WHO jointly run the CAC, which protects the global public health, and makes an effort to balance the food trade relationships.[40,82] Since its commencement in 1963, the CAC is well-known to have produced several food safety standards, guidelines, and codes of practices. As of 2004, the CAC was made up of 188 member countries, one member organization (The EU), 229 observers, and 16 UN agencies.[82] The CAC produced the Codex Alimentarius, which has harmonised international food standards, guidelines, and codes of practice. Further, the Codex Alimentarius has basic rules that food hygiene safety applies within the entire food (supply) chain, from the (original) production to the (final) consumer.[33] The standards of Codex Alimentarius serve as a benchmark to the various national food measures as well as regulations within the legal parameters of the Uruguay Round Agreement.[40] The CAC equally provides the platform for developing countries to join the international community in developing their food quality safety guidelines, standards, and recommendations. Whilst countries are permitted to set their own standards, as sustained by a well-thought-through risk assessment framework/strategy, the CAC continually sets the basis for the equivalency judgment, between the (food quality safety) control systems, which can be considered as under implementation by the various countries.[83]

Importantly, food safety standards are legislatively relevant to the implementation and improvement of QM in the agro-food product industry.[17] In addition, food safety issues across countries equally vary and account for differences in legislation/private sector responses.[84] Enforcing food quality safety standards through legislation also helps establishments/units develop private standards that tackle the complex food supply chain safety issues.[85] Specifically, the private food quality safety standards aim to: a) eliminate multiple audits of food suppliers-manufacturers via having their processes certified; b) improve supplier consistency and standards, so as to avoid failure; c) provide concise information about production processes in case of food incidents; and d) support consumer and retail objectives by transferring their demands to parties upstream the chain.[86] At the international levels, the food quality safety standard helps the food product processors to operate with the commercial as well as contractual arrangements, and to minimise the frequency of disruptive food safety incidents.[51] However, there are still some pressing challenges encountered by smallholder agriculture, specifically concerning the overall growing complexities of private food (quality and) safety standards. The challenges encountered by smallholder agriculture have specifically been found in developing countries.[87] Through food quality safety standards, the small-scale producers are able to effectively integrate into the supermarket supply chains.[88] In addition, it is important to reiterate that food-borne diseases that confront food quality safety pose great challenge to the public health authorities, food industries, and consumers.[89] Thus, food quality safety standards are very important/vital to the global food supply chain. As the efforts continue to ensure food quality safety rise to the global challenges, it is imperative that the policymakers equally persist on the various food industries to comply with the food (quality safety) standards. This is because the final market of the product depends on the several stages of (agro-food) supply chain.[85]

The retail sector within the various chains of agro-food industries are considered useful in elevating food quality safety standards to higher levels. In fact, two voluntary consensus standards, namely Global GAP and British Retail Consortium (BRC) are technical standards of retailers together with their interest groups, which differ from the HACCP or ISO-based standards that have evolved through either the public authorities or inter-government agencies.[90] As the supermarket chains implement their own food safety standards,[91] every agro-food industry/unit has to take full responsibility for its own food quality safety unit. This idea has always been carried out to assure the credibility as well as the effectiveness of the existent food quality safety regulatory framework.[84] In addition, there are the halal and kosher, both have acquired their own quality certification and standards, and are continually and increasingly elevating their quality framework.[92] Practically, food processors should be the ones who determine if the final products meet the prerequisite criteria as prescribed in the stated food quality safety standards. For instance, the sampling plans within the given food industry would have to relay the reports with the decision of whether to either accept or reject the batch of food products. Different regulatory bodies set the criteria for food quality safety and guide how preventive actions within the manufacturing process are defined.[37] The food quality safety standards' focus on characteristic properties of food products should include producer practices within the food supply chain, as well as its traceability. Therefore, to operate within the minimum quality standards (MQS) should be the focus, because of the influence such would deliver to the food market/trade as well as policy-makers. The primary aim of operating within the MQS should therefore be to assure that food sold to consumers fulfils the desired food quality safety requirements.[85] Thus, any food-based QM system should include quality safety standards, which has been well established to serve a wide range of (agro) food products.[91]

Good (food hygiene quality safety) practices relevant to agro-food product industry: Some detailed discussions

Good practices cut across all key aspects of the supply chain processes found within the (agro)food industry.[93] When the job roles of all who deliver quality within the food industry/sector are not clearly defined as well as understood, the integrity of food safety can be compromised. Thus, there is a need to reiterate the importance of good practices in the domain of food quality and consumer protection.[41] Good practices – described in the Codes of Practice, are designed by government bodies representing consumers (e.g., UK Food Standards Agency), producers' organizations (e.g., Europe/AfricanCaribbeanePacific Liason Committee – COLEACP), including importers/retailers' consortia (e.g., British Retail Consortium – BRC, Food Policy Council – FPC, Commission for Instruments and Methods of Observation – CIMO, together with the Euro-Retailer Produce Working Group – EUREP).[28] Within the food systems, these (Codes of Practice) involve the various quality assurance activities, which are consistent with the control of food production (as well as food-related processes).[28]

Summary of previous studies that investigated good (food hygiene quality safety) practices across various agro-food product supply chain and related sectors and respective specific study objectives are presented in Table 2. Good manufacturing practice (GMP), good agricultural practice (GAP), good catering practice (GCP), good hygiene practice (GHP), good laboratory practice (GLP), good retail practice (GRP), good storage practice (GSP), and good transport practice (GTP), comprise the key good practices very relevant to the agro-food product industry. Understanding these good practices remains certainly vital in improving the quality and safety of the agro-food supply chain, especially from the producer and consumer perspectives. Detailed discussion on each (above-mentioned) is hereby presented below.

Good manufacturing practice (GMP)

GMP began with the integrity control of individual activities within the production chains with subsequent positive experiences that have been developed over the years. From its first principles/rules in 1968, the WHO of the UN set the GMP standard procedures that dealt with building equipment, documentation, production, and quality control.[42] As the backbone aspects of food processing operations, the GMP aims for consistency in (food) quality/safety, by providing the basic good practice requirements for environment, facility, and workers.[149] GMP involves practical procedures/processes that would help to optimize the quality system, manufacture, and control of products.[42] Similarly, the GMP guidelines specify the activities as well as conditions food

Table 2: Summary of previous studies that investigated good (food hygiene quality safety) practices, showing various agro-food product supply chain and related sectors, together with respective specific study objectives

References	Good (food hygiene quality safety) practices	agro-food product supply chain and related sector	Specific objective of study
Bernhardt and Raschke [94]	GMP	Cane sugar factories/plants in South Africa	To communicate how GMP can be introduced to a sugar factory
Moberg.[32]	GMP	Refrigerated foods	To identify GMP areas that need consideration in developing, processing and marketing refrigerated foods
Rodmanee and Huang [95]	GMP	Herbal product processing in women's community enterprise at a Thailand province	To assess the current hygiene and manufacturing practice in the community herbal processing enterprise/sector prior to GMP implementation
Arkeman, Herlinawati, Wibawa, and Adinegoro [96]	GMP	Bakery small-medium enterprises in Bogor, Indonesia	To formulate strategy for improving food safety based implementation of GMP within bakery small-medium enterprise
Amoa-Awua et al. [97]	GMP (with HACCP)	Traditional kenkey production in Ghana	To manage the hazards, aflatoxins and enteric pathogens associated with the production of an indigenous African fermented maize
Santana et al. [98]	GMP	Public school catering in Salvador, Brazil	To evaluate the food safety of the services used in free schools and adopt GMP in assuring safe food supply
Cusato, Gameiro, Coarassin, Sant'Ana et al. [99]	GMP (with SSOP and HACCP)	Dairy processing plant located in São Paulo, Brazil	To describe the implementation of food safety system and its challenges within a dairy processing plant
Demirbaş and Karagözlü [100]	GMP (with GHP, HACCP and ISO)	Various dairy plants in Turkey	To survey the level of compliance with the food safety changes/improvements mandated by food legislation in Turkey
Konecka-Matyjek, Turlejska, Pelzner, and Szponar [101]	GMP (with GHP and HACCP)	Food production plants within some provinces in Poland	To determine current situation in implementing GMP (with GHP and HACCP) in food production and processing plants
Martinez-Tomé, Vera and Antonia Murca [102]	GMP (with HACCP)	Salads, which are food considered to be high risk in school kitchens	To establish regulated control GMP (with HACCP) system via checklist on salad production in school kitchens so as to improve food safety
De Lima, Medeiros, Dardin and Stangarlin-Fiori [103]	GHP	Food truck used for food distribution	To evaluate the implementation of GHP in food trucks with and without intervention of a food safety expert
Baluka, Miller, and Kaneene [104]	GHP	Food service facilities in a university	To examine individual worker and institutional hygiene practices and bacterial contamination in food service facilities at Makerere University, Uganda
Jianu and Goleț [105]	GHP	Meat handlers in meat processing units in western Romania	To determine the knowledge of food safety and hygiene and personal hygiene practices among meat handlers and meat processing units in western Romania
Rahman, Arif, Bakar and Talib [106]	GHP	Food vendors in Northern Kuching City, Sarawak	To assess the level of attitude, knowledge and practice and to determine the factors affecting food safety among food vendors in Northern Kuching City, Sarawak
Wambui, Karuri, Lamuka, and Matofari [107]	GHP	Meat handlers in small and medium enterprise (SME) slaughterhouses in Kenya	To determine the GHPs (which include hand-washing, protective clothing, prohibited practices, medical examination and equipment handling) among meat handlers in small and medium enterprise (SME) slaughterhouses
Saad, See and Adil [108]	GHP	Food handlers in the Northern Region of Malaysia	To assess the level of food hygiene practices among food handlers in the Northern Region of Malaysia
Upadhayaya and Ghimire [109]	GHP	Retail meat shops and meat production in Nepal	To assess GHPs in retail meat shops for safe and wholesome meat production as well as understand different roles performed by delegated institutions that ensure quality meat production in Nepal

(*Continued*)

Table 2 (Continued).

References	Good (food hygiene quality safety) practices	agro-food product supply chain and related sector	Specific objective of study
Ifeadike, Ironkwe, Adogu, Nnebue [110]	GHP	Food handlers and establishments in the Federal Capital Territory, Nigeria	To assess food hygiene practices of food handlers, so as to recommend improved food safety, measures and sanitary conditions within food establishments in Federal Capital Territory, Nigeria
Djekic, Smigic, Kalogianni, Rocha, et al. [111]	GHP (with HACCP)	Different food establishments at three European cities – Belgrade, Thessaloniki and Porto	To determine food hygiene level of different food establishments, examine managers' opinion, and justify food hygiene importance via consumers' perception of food safety/hygiene practices at three European cities
Okpala, Nwobi, and Korzeniowska [112]	GHP (with GSP)	Meat industry in Nsukka, Enugu State of Nigeria	To assess butchers' knowledge and perception of good hygiene and storage practices through a cattle slaughterhouse case analysis.
Cortese, Veiros, Feldman and Cavalli [113]	GHP (with HACCP)	Street food sold at urban center in Brazil's major capital	To assess the street foods' compliance (sold in urban center in major capital of Brazil) with international standards for food safety and to provide data to elaborate specific legislation to ensure safety of street food
Ababio and Adi [114]	GHP (with HACCP)	Food handlers in the Kumasi metropolis, Ghana	To investigate the level of hygiene awareness and practices among food handlers in five major communities of Kumasi metropolis, Ghana
Kunadu, Ofosu, Aboagye and Tano-Debrah [115]	GHP (with GCP)	Food handlers in (institutional) foodservice establishment in Accra, Ghana	To evaluate food safety, attitude, knowledge and practice of food handlers from institutional food service establishments (hospitals, boarding of senior high schools, and prisons) in Accra, Ghana
Sinkel, Khouryieh, Daday, Stone, et al. [116]	GAP	Fresh produce farm at Commonwealth of Kentucky, USA	To assess the knowledge of food safety and attitude towards GAP among fresh produce growers at Kentucky, USA
Da Cruz, Cenci and Maia [117]	GAP	Brazilian produce plant	To evaluate the GAP of a Brazilian produce plant based on checklist (from sanitary equipment, handling of agrochemicals, to hygiene levels)
Nurul Islam, Arshad, Radam and Alias [118]	GAP	Tomato production and marketing in Malaysia	To investigate the effectiveness of GAP in the production and marketing of tomatoes in the Cameron Highlands – an important vegetable growing area in Malaysia
Wongsprawmas, Canavari and Waisarayutt [119]	GAP	Fresh and vegetable industries in Thailand	To explore factors hindering the adoption of GAP in Thai fresh and vegetable industry from the perspective of key stakeholders in different tiers of supply chain
Kokkinakis, Boskou, Fragkiadakis, Kokkinaki, et al. [120]	GAP	Greenhouse growing vegetables at some production sites in Greece	To determine efficiency of GAP protocol (AGRO 2–1 & 2–2) in advancing microbiological quality of peppers and tomatoes grown in greenhouses at some production sites in Greece
Marine, Martin, Adalja, Mathew, et al. [121]	GAP	Vegetable production in Delaware and Maryland, USA	To assess vegetable producers' understanding and implementation of GAP (pre-harvest production practices) via commercial growers meetings in 2010 and 2013
Hamilton, Umber, Hultberg, Tong, et al. [122]	GAP	Minnesota vegetable farm producers	To understand barriers to GAP incorporation by Minnesota vegetable farmers of fruits and vegetables and determine extent actual matched perceived practices
Ganpat, Badrie, Walter, Roberts, et al. [123]	GAP	Small vegetable farmers across Trinidad, West Indies	To assess the extent of compliance with GAPs from the recommended protocols governing product/ post-production (practices) among small holder vegetable farmers across Trinidad, West Indies
Rebouças, Santiago, Martins, Menezes, et al. [124]	GCP (with HACCP aspects)	Food handlers and managers of restaurants	To assess the knowledge level, attitudes and practices of food handlers, and knowledge and practices of head chefs and managers in hotels' restaurants of Salvador, Brazil

(*Continued*)

Table 2 (Continued).

References	Good (food hygiene quality safety) practices	agro-food product supply chain and related sector	Specific objective of study
Pichler, Ziegler, Aldrian and Allerberger [125]	GCP (with GHP and HACCP)	Food handlers in catering and restaurants and catering companies in Austria	To detect the most important gaps in knowledge on food safety among food handlers, and to identify possible differences in knowledge levels between food handlers from restaurants and catering companies in Vienna, Austria
Nee and Sani [126]	GCP (with GHP and HACCP)	Food handlers at residential colleges and canteens at campus of Universiti Kabangsaan, Malaysia	To evaluate level of knowledge, attitude and practices regarding aspects of food hygiene and safety among food handlers at residential colleges/canteens at a university campus
Veiros, Proença, Santos, Kent-Smith and Rocha [127]	GCP (with HACCP)	University foodservice canteen	To verify procedures and practices related to HACCP prerequisites at university foodservice canteen (using a checklist based on Portuguese and European legislation)
Garayoa, Vitas, Díez-Leturia and Garcia-Jalón [128]	GCP (with HACCP)	Food handlers in contract catering companies	To assess knowledge, attitudes and practices of food handlers within HACCP implementation system in contract catering companies
Jena and Chavan [129]	GLP	(Useful across/within) agro-food product sectors	To explore the use of GLP principles in different fields of science and its acceptability as well as looking forward to its future perspectives
Lepore and Crawford [130]	GLP	(Useful across/within) agro-food product sectors	To view the events that led to need for GLPs, to provide insights into how regulations were prepared and to describe pertinent aspects of some provisions of final regulations
Wolf and Wolfe [131]	GLP	Fish and related products	To use the application of GLP principles to highlight differences between mammalian and fish studies, and help identify with specific concerns associated with formulation of Standard Operating Procedures (SOPs) for fish projects
Lucero and Siñeriz [132]	GLP	Microbiological and related laboratory linked activities applicable to food (and related) sectors	To reveal the Argentine experience in enhancing biosafety through GLPs considering the growing concerns about safe laboratory practices (at the time of the study)
Hart and John Scott [133]	GLP	Fruits and vegetables commonly consumed in the UK	To further examine factors affecting chromatographic response of carotenoids in fruits and vegetables, which contribute to analytical quantitative inaccuracies/variations, by investigating measurement's reproducibility and robustness using a reference (food) material developed in the laboratory
Allwood, Jenkins, Paulus, Johnson, et al. [134]	GRP	Handwashing facilities, and handwashing training in retail food establishments	To investigate the effect of handwashing training, availability of handwashing facilities and ability of the person in charge (PIC) to
Neal, Binkley and Henroid [135]	GRP	Food service workers in retail food establishments at Houston, Texas USA	To identify factors and behavior that constitute food safety culture among food service workers in retail food establishments at Houston, Texas USA
Jame Wyatt and Guy [136]	GRP	Quality of food retail market stores in Oregon, USA	To evaluate the sanitation using profile scoring form as well as microbiological analysis to explore microbial quality of food retail market stores in Oregon, USA
Strohbehn, Sneed, Paez and Meyer [137]	GRP	Hand-washing in retail food service operations industry	To assess compliance with hand-washing regulations with the consideration of frequency and methods used by sectors of the retail food service operations, which involved hand-washing behavior during menu production, service and cleaning
Picha, Skořepa and Navrátil [138]	GRP (and some related aspects)	Food retail chains in Czech Republic	To assess differences in food choice behavior between regular customer of a specific food retail chain compared to another, using a strategy formulated by consumer cooperative in Czech Republic

(Continued)

Table 2 (Continued).

References	Good (food hygiene quality safety) practices	agro-food product supply chain and related sector	Specific objective of study
Kungu, Dione, Roesel, Ejobi, et al. [139]	GRP (and other related aspects)	Pork retail outlet in Uganda	To map the distribution of pork retail outlets as well as assess their role in foodborne disease transmission, specifically, practices associated with hygiene related infrastructure, workers and equipment
Ajani and Onwubuya [140]	GSP	Maize storage practices among farmers in Anambra State, Nigeria	To assess the use of indigenous maize storage practices among farmers in Anambra State, Nigeria
Shabani, Kimanya, Gichuhi, Bonsi, et al. [141]	GSP	Maize storage practices in Handeni District, Tanzania	To investigate the maize storage (and consumption) practices of farmers, which included implications for mycotoxin contamination of maize flour in Handeni District, Tanzania
Hell, Cardwell, Setamou and Poehling [142]	GSP	Maize storage practices in four agroecological zones of Benin, West Africa	To determine the effect of storage practices on aflatoxin contamination in (300) maize farmers stores in four agroecological zones in the Republic of Benin, West Africa
Katundu, Hendriks, Bower and Siwela [143]	GSP	Small-scale organic potato farmers in KwaZulu-Natal, South Africa	To investigate the effects of traditional storage practices on the quality of potatos of small-scale organic farmers in rural KwaZulu-Natal of South Africa, based on preference of products comparing conditions over a 6-week period
Martins, de Campos Leite, Martins, da Silva, et al. [144]	GSP	Seafood storage at 21st Supply Deposit of Brazilian Army, São Paulo, Brazil	To evaluate good (seafood) storage practices in the 21st Supply Deposit of Brazilia Army located in São Paulo, Brazil, identify issues of non-compliance that compromise food quality and propose solutions
Uplap, Khandave, Thorat and Lohar [145]	GSP	Food grain storage involving farm women of Pune District (Maharashtra), India	To determine the knowledge and adoption of food grain storage practices by farm women of Pune District (Maharashtra), India
Evans and Redmond [146]	GSP	Domestic food handling and storage practices associated with ready-to-eat (RTE) foods in older adults	To ascertain older adults' cognition in relation to domestic food handling and storage practices that may increase the risks associated with *Listeria monocytogenes* in RTE foods
Balzan, Fasolato, Cardazzo, Berti, et al. [147]	GTP	Fresh and frozen food chain in North East of Italy	To gain insight into ways consumers purchase, transport and store fresh and frozen food in North East of Italy
Ackerley, Sertkaya and Lange [148]	GTP	Food commodities transportation and holding	Using expert opinion elicitation to assess food safety hazards and preventive controls associated with transportation and holding of food commodities

manufacturing processes required to ensure the food production process adheres to the prerequisite safety standards.[47,150] For the reason that every element of food production has to be defined in advance, specific resources have to be delivered in its appropriate place, quantity and time, and utilised as intended.[33]

With respect to agro-food products, the GMP's guiding principle is that the prerequisite quality has to be built into the (agro-food) production schedules through the standard operating procedures (SOPs). Furthermore, the SOPs have to consistently perform under the same (standard) conditions to meet up with the final specifications.[151,152] Globally, the GMP regulations do differ, for example, the FDA in the US was key in setting-up GMP regulations. Other countries, such as Australia, Japan, Singapore, including the EU, have their own GMP regulations. The WHO's GMP regulations apply to many countries that do not have their own GMP requirements.[153] In addition, the GMP is equally applicable to the agro-food products that require refrigeration. In the US for instance, both the GMPs and federal regulations do differ in some specifics, an example, the acceptable upper-temperature limits of refrigerated food products. In addition, to maintain the organoleptic and quality characteristics can help to realise the significant shelf life extension of the refrigerated (food) products.[32] Within the agro-food product supply chain, the manufacturing facility should be made to adhere to the GMP plant sanitation guidelines. Within the manufacturing process, the GMP is therefore very critical particularly in the product development stage(s).[32]

Besides having the technological capacity to tackle food industry challenges, GMP under the specified conditions can serve as a food process guide.[154] The GMP considers the development, processing, and marketing phases within the food supply chain.[32] Elements of GMPs can include pest control, sanitation procedures, sanitary design and maintenance of equipment/facilities, training in personnel hygiene, and warehousing/distribution.[155] Within the food industry, the GMPs would help to address the factors within the manufacturing process, such as personnel, building, premises, apparatus/machinery, documentation, quality control, that generally influence product quality/monitoring.[152] From the refrigerated foods to the food processing facilities, the GMP effectively monitors the safety components, for example, the microbiological hazards especially in manufacture and distribution.[32,156] In the agro-food processing plants, the GMP manuals would facilitate continuous evaluation and improvement. In addition, the GMP's would help the food industries to adopt measures that guarantee products' conformity as well as safety, in the adherence to the specific regulations.[151]

To implement the GMP procedures in the food industry would require a wide range of general measures, already described by the Codex Alimentarius, which can include: a) hygiene in primary production; b) hygienic design of equipment/facilities; c) control of operations, maintenance and sanitation practices; d) personal hygiene; e) transportation; f) product information; as well as g) consumer awareness/training.[151] Whereas the food industry adopts varying procedures, the hygiene practices continually adhere to general Codex Alimentarius guidelines.[151] Implementing the GMP in the dairy processes is key in reducing the biological, chemical, and physical hazards that contaminate (dairy) products.[151] Implementing the GMP should be seen as a continuous process that is largely based on the PDCA cycle, that is, *P* = Plan, D = Do, C = Check, and A = Action, which would directly relate with the four key steps, namely: a) there should be an initial diagnosis; b) there should be an elaboration of the road map; c) both diagnosis and roadmap will help to address non-conformities; d) the corrective measures under implementation should be subject to a re-evaluation.[97,151,157] Using a GMP regulated checklist, both initial diagnosis and re-evaluation of corrective measures can be implemented through the audit of processing facilities. Likened to a road map, the implementation of GMPs would provide tangible benefits, which could be assessed by key candidates such as microbiological indicators, pre- and post-implementation costs, etc.[151]

The GMP alone or combined with HACCP, etc., was investigated in bakery small-medium enterprises, [96] foodservice kitchens,[98,102] traditional indigenous food production,[97] dairy plants,[99,100] and other food production plants,[95,101] which had a wide variety of outcomes (Table 2). Martinez-Tomé, Vera, and Antonia Murcia[102] used GMP + HACCP to check food production in school kitchens and obtained reductions in the microbial population of examined cutting boards, tables, etc., as food handlers improved in food safety practices. By formulating a strategy for improving food safety through the GMP implementation, Arkeman et al. [96] used the SWOT analysis and were able to identify the significant aspects of supporting elements as well as constraints. The complete analysis brought about the five alternatives formulation strategies, which these authors believed could help in improving the food safety practices based on the implementation of GMP. The five alternative formulation strategies included: a) creating promotional area of healthy safe original (Bogor) foods in a strategic area for (SP-IRT) certified bakery SME products; b) keeping the SP-IRT registration fee waiving policy; c) creating both local food-nutrition strategic action and industrial development strategic plans; d) creating a planned training program for food safety extension workers and control personnel; and e) conducting periodic annual control. In another study conducted in Ghana specific to the traditional production of kenkey, Amoa-Awua et al. [97] reported that GMP was applicable in the management of mycotoxin contamination of maize (and maize products). The application of GMP (and HACCP) was found effective in assuring the quality safety of kenkey in the traditional processing of maize into kenkey. Santana et al. [98] sought to establish how adopting GMP could assure safe food supply to students, and this was conducted by evaluating food safety services used in free school meal preparation. The results, based on a checklist survey, showed that about 80% of the food safety services prior to adopting the GMP were classified as 'poor'. Therein, the samples measured for microbial analysis that showed high aerobic plate count (APC) as well as the presence of thermotolerant coliforms and *Staphylococcus* TNase-coagulase positives. By adopting the GMP procedures, the schools could achieve higher survey scores, together with the respective reductions in quantity of APC, (thermotolerant) coliforms in the meals, as well as the non-isolation of *Staphylococcus* spp.

By assessing both hygiene and manufacturing practices, Rodmanee and Huang [95] reported that a community (herbal product) enterprise in Thailand fell short of its required GMP standard. It was to tackle this situation that an action plan that considered the participation of every stakeholder was developed. In a Poland study that sought to decipher the status of GMP and its related rules, Konecka-Matyjek et al. [102] found that whilst some food production plants were in the process of implementation, others were still thinking of doing so. Moreover, Bernhardt and Raschke[94] delineated useful benefits in the sugar factory by introducing GMP. Examples of such useful benefits included the reduction in waste as well as enhancement of profit revenues. Of course, there are aspects of GMP that could be applied in developing, processing, and marketing refrigerated foods to improve ingredients, product development, processing, storage, and distribution of refrigerated foods.[32] By combining GMP, HACCP, and other related ones, Demirbaş and Karagözlü [100] surveyed the level of food safety (compliance) in dairy plants in Turkey. These workers showed that the food legislation would likely suffice, especially to ensure the compliance with food safety procedures. But not all the dairy processes had incorporated the government-imposed regulatory practices. However, technical support was suggested as needed to enhance the food safety infrastructure for the dairy industry. Similarly, Cusato, Gameiro et al.[99] showed GMP (+SSOP, etc) implementation resulted in a significant reduction in yeast and mould count in the dairy processing plant. Additionally, the feasibility of small-scale food industries to implement such food safety systems was delineated at that study.

Good hygiene practice (GHP)

GHP guidelines specify that the hygiene activities have to be continually monitored at all the food supply chain processes as well as stages.[47,150] In addition, the GHP guidelines would constitute (some) practical procedures that should help to return the processing environment to its original condition (disinfection and sanitation programs).[42] In addition, the GHP has general principles, which have been linked to food hygiene, as legislatively underpinned by EU Regulations No: 178/2002, No: 852/2004, No: 853/2004. No: 854/2004 as well as Codex Alimentarius.[127] In addition, the GHP has an exhaustive list of measures prerequisite to other food quality and safety management systems.[158] Under the EU hygiene regulation directive, the GHPs indicate the consumer has a direct food safety responsibility. This has allowed the food industry to possess some form of flexibility, so as to meet up with the obligations, through the use of the more appropriate prerequisite approaches and standards.[159] In order to ensure food hygiene from farm to fork, the GHP gives a great deal of emphasis to the hygiene control, especially at each stage of the food supply chain.[160] Regardless of the location/settings, to adapt the GHP requires sufficient information about specific food handling, preparation, and storage procedures that would reduce the food hazards/risks.[161] GHP, especially in the food industry, provides the conditions/measures required to control hazards that make foodstuffs fit for human consumption.[158] Besides GHP controlling food safety risks,[156] the concerns of cross-contamination continue to be among the key challenges for GHP.[161]

GHP's compliance helps to increase the awareness of food microbiological challenges.[162] If the food industry/sector management takes GHP seriously, provides the time/resources, and makes available the rewards for good performance, the employees would most likely emerge more diligent in their responsibilities. The GHP can, therefore, take the form of an appraisal system, especially for employees, supervisors, and managers. While the GHP violations should be handled in a disciplinary fashion, there should be some form of incentive put in place as a reward to the high-level (GHP) performance. In addition, developing and monitoring the hygiene procedures with the staff can serve as an effective means of winning (staff) commitment.[159] In the process of applying the GHP, it is necessary that both storage and pre-storage practices be prioritised as this remains very key if the contamination problem is to be reduced.[93] In this way, the GHP can serve as a positive influence on the wholesomeness of food, as well as ensuring the optimal hygiene condition of (food) production processes.[163] In meat processing, for instance, the GHP posits as a hygiene-based on-farm measure to control interventions. The GHP can also be applied at multiple points within the (food) supply chain, and implemented in cycles resembling a sanitation-like activity, which concurrently runs with the application of sanitisers.[93]

The GHP framework can take the form of either a brochure or manual , which should be an easy-to -read as well as easy-to-understand document especially for the local (farmers/industry/supply) chain workers and consumers. From this approach, the awareness about cross-contamination is increased, particularly to the benefit of the agro-food product industry.[162] The GHP lays this foundation, especially in handling and storage as well as inspection of incoming materials, which would ensure that the production plans, together with the suppliers' specifications can be met.[93] For long, the periodic assessment of food hygiene training and subsequent checks especially for the managers has been a standard requirement, [164] which has ensured the knowledge update(s) about the food hygiene practices continue got provided. As an example, the street food vendors need to be continually informed about GHP especially at all the stages of the production chain.[113] Therefore, the GHP applied within the foodservice requires some form of verification, which has to be conducted using a checklist approach.[127] In Uganda, for example, the GHP served as a candidate used for quality assurance rules, which formed part of the fish safety compliance and standards, which has helped to improve product quality safety.[165] In line with this, the design and layout of food retail/industry premises should allow for the GHP implementation. Further, the internal structures and equipment should therefore be built of materials that allow for easy cleaning, disinfecting, disinfecting, and maintenance.[166]

GHP alone or combined with GCP, GSP, HACCP, etc. investigated food handlers, [108,110,114,115] specifics like meat handlers, [105,107,112] different food (service) establishments,[111] like retail (meat) shops, [109] food truck, [103] food vendors,[106] urban street food sellers[113] and foodservice facilities[104] with variable outcomes . Ifeadike et al. [110] assessed the food hygiene practice of food handlers in the FCT Nigeria, and found that majority washed their hands after using the toilets and underwent regular medical checkups, with much less (food handlers) either using disinfectants and sanitizers or checked the food temperature with a thermometer at the workplace. In another study, Saad, See and Adil [108] assessed the level of food hygiene practices of food handlers in the Northern Region of Malaysia. These workers found the food hygiene practices to be consistent with the requirements of the Food Act 1983 and Food Hygiene Regulation 2009, which demonstrated that food handlers were very important key players in the GHP implementation particularly within the foodservice industry. Indeed, when the food handlers become familiar with the foodborne diseases and they are able to highlight the preventive measures, it is likely to reflect on their personal hygiene status. This makes formal training (of good hygiene practices) [114] as well as consistency in work experience/ exposure to food handling [108] very essential. Upadhayaya and Ghimira [109] reported that the majority of meat handlers had no regular health checkups and demonstrated the knowledge gap about the Slaughterhouse Meat Inspection Act 1999 of Nepal. Implementing this (food hygiene) regulation would play a crucial role to improve both the hygiene practices and quality standards of the meat products/shops. Rahman et al. [106] assessed the level of attitude, knowledge, and practice of food safety, and reported both age and ethnicity as important factors for food safety knowledge, which altogether would influence food safety practice. Jianu and Goleţ [105] determined the knowledge of food hygiene and safety in the meat processing unit in Romania and reported meat handlers deficient in identifying both chemical/microbiological hazards and hand hygiene aspects. Significantly, the level of (food hygiene and safety) knowledge correlated positively with the practice of meat handlers. Training programs with an emphasis on the identification of risks to food safety and hand hygiene were recommended.

Okpala, Nwobi and Korzeniowska [112] assessed the butchers' knowledge and perception of GHP and good storage practices (GSP) using a cattle slaughterhouse case analysis. Their findings revealed that butchers were male, with more than 5 years of slaughterhouse experience, and strongly familiar with GHP and GSP. Further mentioned in that study, butchers were able to provide examples that demonstrated knowledge and perception of GHP and GSP. Additionally, the perception aspects of GHP and GSP were correlated more, compared to knowledge and knowledge versus perception. Kunadu et al.[115] evaluated the food safety attitude, knowledge, and practices in foodservice establishments. These workers reported the food handlers' attitude towards the food safety as generally negative, raising such concerns like a) lack of knowledge of contaminants/contamination; b) lack of knowledge about appropriate holding temperature; c) poor food hygiene safety practices; and d) infrequent handwashing during food preparation either after coughing or sneezing. To alleviate this challenge, these workers recommended the need for continuous risk-based training to educate and effect behavioural changes among food handlers. Such training would bring about a positive attitude towards food safety and as a consequence, promote the overall good (food hygiene safety) practices. Baluka, Miller, and Kaneene [104] examined individual workers and institutional practices in foodservice facility and reported the (foodservice) personnel with higher education levels showed the better attitude/knowledge of food safety, although the latter did not corroborate with the microbiological acceptability of food samples (at the foodservice facility). Regards to the food vendors, Djekic et al. [111] associated the major differences in food hygiene levels in food establishments with HACCP (implementation) and not with size and type of establishment. In another study, Cortese et al. [113] reported the usefulness of specific local and national food laws in protecting consumers and ensuring continuous training of food vendors so as to address the inadequacies of food quality and safety. Investigating GHP implementation in food trucks used for food distribution, De Lima et al.[103] reported that increases in food safety awareness would help food truck owners and staff to value investing in food safety, which would ensure an effective reduction of contamination risks.

Good agricultural practice (GAP)

GAP was first started in 2003 by FAO.[160] The FAO referred GAP as practices that address economic, environmental, and social sustainability for on-farm processes to bring about quality and safe food (and non-food agro-products).[167] As a selection of methods of land use, GAP can best achieve a number of agronomic and environmental sustainability objectives in primary food production.[42] According to US FDA, GAP aims to reduce the possibility of microbial contamination associated with such practices like the application of raw manure, contaminated agricultural or processing water, unhygienic practices by farm holders and workers, as well as poor sanitary facilities.[168] GAP is considered among essential good practices especially to curtail hazards that make their way through the food supply chain.[160] In recent years, GAP codes, standards, and regulations have developed for a wide range of commonalities so as to codify agricultural practices even at the farm level. Some objectives of GAP codes, standards and regulations can include: (a) Ensuring quality safe food chain produce; b) Capturing new market advantage via governance modification of supply chain; c) Improving worker health, working conditions, and natural resource usage; d) creating new market opportunities for farmers and exporters, especially in developing countries.[160]

Originally, the criteria to define GAPs were developed for on-farm production methods and resource use. Recent years show that organisations would promote voluntary private standard (PS) schemes and apply them across the agri-food supply chain.[169] With the growing concerns over food quality, safety and sustainability among consumers, retailers, governments, processors, as well as growers, the GAP would serve as an effective measure that ensures, not only the quality/safety of products but also create a number of new market opportunities that improve the farmworkers' health and working conditions [168] Four pillars that represent GAP can include: a) economic viability; b) (agricultural) environmental sustainability; c) social acceptability; and d) food quality/safety. GAP can also have the following objectives: a) ensuring food safety; b) building consumer/customer confidence; c) capturing new market; d) judicious use of natural resources; e) maintaining worker health and welfare; f) income generation; g) enhancing international trade; and h) risk assessment.[168]

The GAPs, through the use of Codex Alimentarius Commission's code of practice for fresh fruits and vegetables (CAC/RCP 53–2003), would involve all activities in and around the agro-food farm fields before, during and after harvest/production (that is, water quality, personnel hygiene, manure composting, etc).[170] GAP can be harmonised with food safety standards within a given supply chain, which would allow for audits by a credible third party acceptable to all produce buyers, so as to reduce the audit burden on growers.[168] Through agricultural practices and management systems linked to microbiological contamination of lettuce in conventional production systems, Bartz et al. [171] considered GAP as among food safety management systems, which at the farm level would reduce/ prevent bacterial contamination of fresh produce. Despite this, GAP ought to be conducted in a step-wise manner, and based on the risk associated with individual fruits and vegetables, and available scientific data.[117] Despite the voluntary nature of GAP certification and its compliance among foodborne pathogen decontamination strategies, the use of audit structures across small-scale farmers might still appear low, which makes (GAP) food safety principles yet to gain traction.[116]

From Table 2, the GAP studies investigated vegetables[142,143,144,145,146] but could also apply to specifics like tomato production [118] or broader, like fresh produce[116] and produce plant(s),[117] which resulted in various outcomes. At a greenhouse growing pepper and tomatoes in Greece, Kokkinakis et al. [120] showed that the GAP protocol AGRO 2–1 & 2–2 could reduce the microbial hazards for consumers and help establish practices in compliance with the basic Euro Retailer-produce GAP (EUREPGAP) requirements. At a vegetable production in both Delaware and Maryland of USA, Marine et al. [121] reported that implementing the GAP might not necessarily bring about differences in food safety practices with respect to farm-scale or production year, and economic constraints might not also be considered an obstacle. Conducting investigations involving the Minnesota USA vegetable farms, Hamilton et al. [122] demonstrated that incorporating GAP measures would help to reduce the risk of domestic/wild animals' entry into the fruits and vegetable areas. In another study, Nurul Islam et al. [118] revealed large-scale tomato farms in Malaysia that utilised GAP practitioners obtained improvements in both income and productivity compared to non-GAP ones. Indeed, the GAP was found an effective candidate, although not completely so considering that the small-scale farmers still encountered a number of constraints, for example, the lack of access to credit for investment as well as technical support. Recommendations like extending, monitoring, and upgrading of Malaysian certification were suggested as possible way out to help assure the product quality. Other workers like Wongsprawmas, Canavari and Waisarayutt[119] understood that consumers' demand for fresh vegetable production could help promote the GAP adoption to producers in Thailand. In another study that involved the fresh produce farms at Commonwealth of Kentucky USA, Sinkel et al. [116] opined that even when the majority of (fresh produce) growers were familiar with GAP, the additional education was essential to advance their understanding of food safety practices. Based on a food safety checklist, da Cruz, Cenci, and Maia [117] evaluated the GAP of Brazilian produce plants and reported the production units did not conform to the GAP program items. Therefore, a corrective action plan was deemed necessary, in order to improve both quality and safety of (obtained) raw produce. By studying the smallholder vegetable farms across Trinidad of West Indies, Ganpat et al. [123] established that, in the situation where the compliance to GAP appeared low among the farmers, to produce high quality and safe vegetables would pose a challenge, and require better-educated extension service for improved GAP compliance.

Good storage practice (GSP)

GSP involves the practical procedures/processes that ensure the appropriate handling of foods, regarding the implementation and control of the product storage consistent with the defined regime-(s), and prior to their use.[42] Applicable to a wide range of sections/units, the GSP should consider all measures of distribution and storage of food products to sustain its intended nature/quality to a large degree when it reaches the consumer. GSP components can involve components like documentation, personnel, stock management, storage facilities, etc. Specifically, for storage to meet the needed requirements, the respective areas have to be assigned as the sampling of products, dedicated to the specific product conditions, and differentiated based on the specific product categories.[172] The storage environment should have prerequisite monitoring points, in addition to the effective humidity and temperature control measures. Specifically, the temperature requirement of the storage environment must comply with the labelling standards, without any compromise to the quality/safety of (food) products. In food control (sections/units), storage systems should systematically provide sufficient passage for inspection and easy movement given by proper labelling and product release mechanisms.[172]

GSP can also interact with both GAP and GHP, and a schematic representation showing this interaction as applicable and relevant to a typical cattle slaughterhouse in Nigeria is shown in Fig. 4. Specifically, each of these good practices have reflect very important aspects of the typical cattle slaughterhouse. For instance, GAP will involve the arrival of cattle to the slaughterhouse, and in good condition. Then, GHP will involve the slaughter preparation, the actual slaughter process, and subsequent carcass handling thereafter. Then, GSP will involve all aspects of carcass storage, distribution, as well as refrigeration. Additionally, GAP will involve the cattle rearers, whereas GHP and GSP will involve the slaughterhouse activities. The interaction of GAP, GHP, GSP demonstrates the importance and relevance of these practices to the typical (Nigeria) cattle slaughterhouse, [112] and that is why it is deemed the compulsory (hygiene/safety-related) aspects of QM. Besides, the personnel that operate within the food storage section must have the

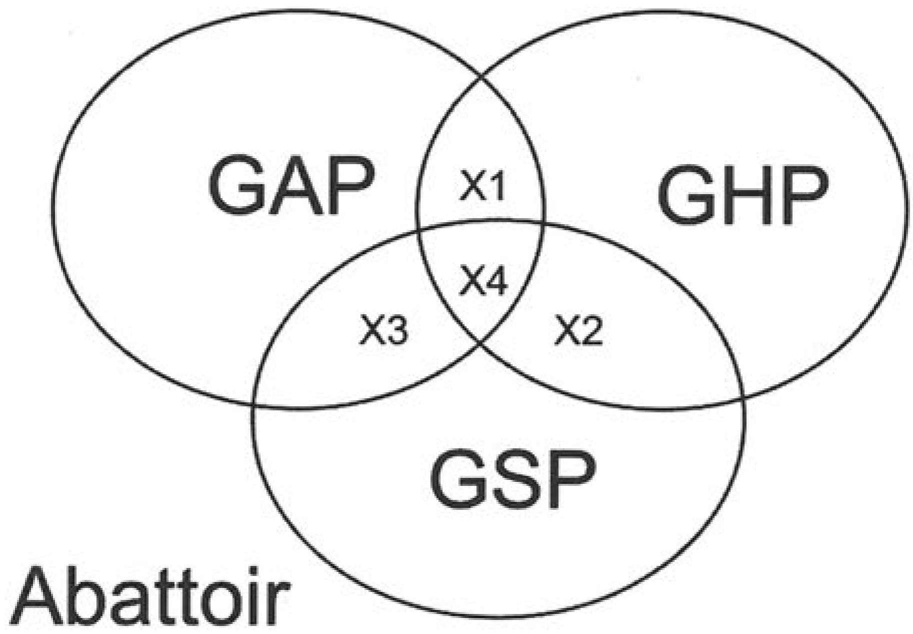

Figure 4. Schematic representation of the interaction between GAP, GHP, and GSP applicable and relevant to a typical cattle abattoir/slaughterhouse in Nigeria. GAP = Good Agricultural Practice, which can involve the humane handling of cattle as well as pre-slaughter keeping of cattle at lairage; GHP = Good Hygiene Practice, which can involve slaughtering activity, as well as carcass splitting and inspection activities; GSP = Good Storage Practice, which can involve carcass storage and refrigeration; X1, X2, and X3 represent the interactive spaces of GAP x GHP, GHP x GSP,, and GAP x GSP, respectively. Additionally, X4 represents the interaction of GAP x GHP x GSP (Source: Okpala, Nwobi & Korzeniowska [112])

experience and should be able and healthy. They should be in a sufficient number so as to avoid exhaustion/overwork. The GSP training can range between basic (storage management/safety hygiene) and specific (computerized stock management) aspects, inclusive of documentation procedures and control systems. The GSP makes written procedures available for returned (agro)food products, which enhances investigations/evaluations of quality and safety, via labelling and segregation of returned goods. Similarly, there is the food products' disposal that involves the written procedures, especially how it should be handled, and consistent with the company and country regulatory requirements.[172] Besides, the organizational workplace should be held to very high discipline and standards, so as to avoid as well as minimise customer complaints of food product(s)/service(s). When such complaints emerge, however, there must be careful and thorough investigation consistent with the laid down procedures. In addition, the responsible person handling the complaint/matter should possess adequate knowledge as well as experience, and importantly, the authority to decide the measures to take/be taken.[172]

In the agro-food product industry, the GSP provides the platform to classify defects of (food) products, namely: minor, major, and critical defects. Whilst the critical defects are those products that are deemed spoiled and require immediate action, the major defects are when the product does not conform to the required standard, whereas the minor is such that there is no important effect, e.g., lack of labelling.[172] In addition, the GSP provides the platform for food product recall, where the responsible person either removes and or withdraws a particular food product from the distribution chain/line. The removal and or withdrawal (of food product) may be due to central quality defects with potential consumers' health risks of the foodborne pathogen. In addition, the GSP provides the platform to recognise various food production staff and their corresponding duties/responsibilities. The quality control manager has to be responsible for assigning qualified recall teams to develop recall strategy.[172] From , GSP studies investigated farm maize storage, [140–142] food grain storage of farm-women,[145] traditional storage practices of small scale organic potato farmers,[143] food handling and storage practices associated with ready-to-eat (RTE) foods,[146] and seafood storage at a supplied deposit, [144] which has reported various outcomes.

Assessing farmers' use of indigenous maize storage practices in Anambra State-Nigeria, Ajani and Onwubuya [140] reported farmers used indigenous technologies such as basket, bare floors, among others for storing the maize. The use of materials free from termite, clearing surroundings against fire disasters, as well as the use of durable materials treated with insecticide, helped to tackle the maize storage challenges. In addition, an appropriate and affordable storage structure was deemed necessary for the maize farmers to avoid the produce wastage during the storage periods. Hell et al. [142] studied the storage practices' influence on aflatoxin contamination in maize in four agro-ecological zones in the Benin Republic. The results showed those cultivated in the Southern Guinea and Sudan Savanna, were associated with higher aflatoxin levels. Further, lower aflatoxin levels resulted when storage or cotton insecticides, mechanical means or smoke to protect pests, or cleaning of stores before loading them with new harvest were applied. Shabani et al. [141] investigated the maize storage and consumption practices of farmers in Handeni District, Tanzania, and reported the majority of farmers (95%) stored the maize in the house using roofing and sack methods. Insects and rodents were among storage challenges. The preponderance of storage practices was considered unfavourable to mycotoxin reduction in stored maize. Area-specific farmer training regarding recommended storage practices includes storage methods, effective management of storage pests, healthy maize preparation, and consumption practices.

Studying both knowledge and adoption of food grain storage practices in Pune District (Maharashtra), Uplap et al. [145] found the majority of farm women adopted the method of sun-drying followed by the method of separation of infested food grains, followed by the method of sieving food grains, and followed by the method of separation of broken grains. Investigating the traditional storage practices on small-scale organic farms, Katundu et al. [143] found the sensory panelists' significantly preferred the in-situ stored potatoes over those stored in both the farmer's house and controlled storage. The in-situ storage would desirably maintain the sensory properties of potatoes, by sustaining the low sugar levels and high starch content. Investigating the storage practices of ready-to-eat (RTE) food products and risks associated with listeriosis, Evans and Redmond [146] reported that, despite 79% of older adults having positive attitudes towards the refrigeration, about 84% appeared unaware of recommended temperatures (5 °C). Also, about 72% knew that the 'use-by' dates indicated food safety, whereas about 67% considered it safe to eat food beyond 'use-by' dates. Older adults, although knowledgeable of some key (storage) practices, self-reported potentially unsafe practices when storing RTE foods at home, which may increase the risks associated with *L. monocytogenes*. Assessing the frozen seafood good storage practices in the 21st Supply Deposit of the Brazilian Army, Martins et al. [144] found that the cold stores' temperatures could not sustain the (seafood) products within the required preservation standards. The seafood storage protocol (of 21st Supply Deposit) appeared not able to guarantee the conformity of the temperature. Implementing the hygienic-sanitary self-control storage program was suggested, in order to improve the food safety culture, which would involve applying a checklist (RDC 275/2002) that evaluates the percentage compliance with good practices.

Good catering practice (GCP)

GCP consists of practical procedures in catering, essential steps required to ensure food served is always safe and wholesome.[42] Within food safety and quality assurance, GCP forms part of food processing, having practical catering procedures. GCP guidelines focus on essential steps required to ensure the food served remains safe and wholesome.[41,160] Given that the catering and retail go together within the food supply chain, the relevance of GCP must not be taken for granted.[162] GCP within kitchen processes in the restaurants and food/beverage companies brings together food and drink processes/transfers, including diverse related production units. In batch cooking of catering companies, GCP can employ some aspects of GMP, especially for the large (food) catering processes. As such, hygiene, quality, and safety procedures/systems, as well as legalities guarantee the assurance of food safety.[173]

When GCP forms a part of a certification framework, the certificate holders will have benefits such as a) strengthening of the public image of the individual/company; b) competitive advantage (within the catering sector); c) demonstrable evidence of working under hygienic conditions; d) strengthened food security across employees; e) ability to fulfil the legal requirement as per food standards; f) strengthened consumer's image to food company/employer; g) increased work efficiency within the catering/food industry; and h) motivated employees within the catering/food company.[173] In large catering processes, GMP implementation has always been deemed mandatory. Through this, GMP is able to provide the essential foundation for the efficiency of important food safety catering standards. To consumers, the GCP certification demonstrates a commitment to producing quality safe food. Such certification provides a comprehensive and cost-effective approach in developing a successful food safety management system (FSMS), which is compliant with the food safety regulations.[174]

The GCP studies alone or combined with GHP, HACCP, etc., shown in , which investigated food handlers in the canteens/restaurants,[124,126,127] catering companies[128] or both (that is, restaurants and catering companies combined),[125] showed varying outcomes. Evaluating canteens' level of attitude, knowledge, and practices of food hygiene and safety in a Malaysian university, Nee, and Sani [126] reported that food handlers possessed a good knowledge of personal hygiene. By defining foodborne disease, the food handlers were shown to possess a positive attitude towards food hygiene/safety. It also demonstrated their ability to control/prevent foodborne diseases. In another study, Veiros et al. [127] reported the canteens within the acceptable range given by a global score of 62% based on the food hygiene quality checklist of Portuguese and European legislation used in verifying practices/procedures related to HACCP prerequisite. Food handlers in that study required improvement, especially in the preparation and distribution of foods, as well as the cleaning, and quality control aspects within the canteen facilities. Food hygiene/quality checklist could improve quality control of food production in catering establishments, especially hygiene and sanitary quality of meals. Detecting the most important knowledge gaps about food safety in catering and restaurant companies, Pichler et al. [125] reported the food handlers that undertook the annual training were found to possess a higher (food safety) knowledge. Even with the annual training, there would still be some substantial knowledge gaps, for example, the correct temperature for cooking, holding, and storing foods. In restaurants in Salvador – Brazil, Rebouças et al. [124] reported that even though food handlers possessed relatively high attitude, knowledge and practice of personal hygiene, it would not be so for both chefs and managers as their knowledge might fall short, even when majority possessed food safety training certificate. Garayoa et al. [128] revealed that, in a good number of kitchens in some Spanish catering companies, when incorrect hygiene practices became systemic, to implement the HACCP system presented inherent difficulties. These were corroborated by the lack of well-trained personnel and the lack of motivation of workers. Such inherent difficulties could however be tackled if the adequate educational programs and funded grants were to be provided towards actualising the HACCP implementation.

Good laboratory practice (GLP)

GLP was first presented to FAO Committee on Agriculture in 2003 as an official regulatory concept that involved a qualitative system, as well as governing organisational conditions/processes within the prerequisite analytical-oriented framework, which would allow for the monitoring, performing, planning, recording, and reporting studies [28,42] Specifically, the object of GLP is to promote both the quality and validity of test data, which arose as a result of the concerns of the validity of non-clinical safety data, which had been submitted to the FDA, at those earlier times.[28] All processing/testing methods and the corresponding equipment/facilities that required the standardisation and validations underlined the core of GLP, which is based on the scientific principles and practices.[175] Regulatory agencies like FDA and US Environmental Protection Agency (EPA) require that the conducted (analytical/laboratory-oriented) studies accord with the GLP. Further, the GLP principles of the Organization for Economic Co-operation and Development (OECD) apply to all OECD countries.[175]

Evaluating the GLP-related safety procedures should include a systematic weight-of-evidence as well as framework-like review, which considers such (evaluation) factors like a) verification of measurement processing data and methods; b) control of variables that could affect the food (production) measurements/processes; c) corroboration among studies (applicable to the situation of food-related studies); d) power (both biological and statistical); e) biological plausibility of results; and f) uniformity among (food) substances with resembling/similar attributes and effects.[175] Quality control procedures, quality assurance reviews, and facility inspections employed would help to enforce as well as monitor the GLP compliance. In addition, the detailed processes of GLP among others aim to provide the regulatory agencies increased confidence, particularly to authenticate both the quality and relevance of safety decisions.[175] Besides, the GLP employed in the laboratories, would form the backbone of various experimental studies.[176]

From Table 2, the GLP studies are shown to involve fish and related products, [131] fruits and vegetables (commonly consumed in the UK),[133] microbiological and related laboratory activities (applicable to food and food-related sectors)[132] as well as those applicable to a wide range of agro-food product sectors.[129,130] Jena and Charan [129] showed that the GLP can broadly apply to any relevant discipline in science, to cater to the demands/needs of experimental objectives, generate quality data as well as facilitate reproducibility. To enhance its international acceptability, the GLP has shown a useful way of promoting the reliability and reproducibility of text-related data. With respect to fish and related products, Wolf and Wolfe [131] showed the GLP principles could highlight differences between fish and mammalian studies. These workers found merits in adhering to GLP as it helped in developing the study-specific 'Project Sheet', which would contain all the instructions not spelled out in the study protocol. This study-specific 'Project Sheet' would thereafter serve as an ad-hoc version of standard operating procedures (SOPs). With respect to fruits and vegetables, Hart and John Scott [133] understood that experimental factors could affect the validity of data, for example, 'peak response' specific to their experiment, which likely contributed to the 'between' and 'within' laboratory variations. Both the development and use of standard reference materials were suggested as useful candidates that can significantly improve the data quality. With respect to microbiological and related laboratory activities, Lucero and Siñeriz [132] showed GLP training courses (applicable to food and its related sectors) could help bring about useful change in work habits, improve laboratory work safety, and overall, motivate work. Whilst the microbial laboratory personnel require training, especially in the proper use of experiments and procedures, it is essential that (national) institutes continue to strengthen the networking effort, so as to increase the (laboratory-oriented) capacities. According to Lepore and Crawford, [130] GLP program instituted by FDA was purposed to ensure the integrity/quality of (submitted) safety data, particularly towards the approval of regulated products, e.g., food additives. GLP program at that time, regulations were hoped to increase public confidence, especially in the FDA decision-making, so as to ensure the safety of products approved for the consumer market.

Good retail practice (GRP)

GRP involves the practical procedures and processes that ensure the delivery of requested/right product(s) to the correct addressee within a satisfactory time period and at the required conditions. This would employ tracing systems that detect faults, to enable an effective/efficient recall procedure.[42] Well-known to occupy a great portion of the agro-food product industry, the retail sector increasingly holds multimillion-dollar food chains.[177] Given the localised nature of food production, the GRP is largely seen to portray a 'closer' connection with the point of production that supports the local economy. Food produce supply can be either direct channel, e.g., farm shops, local retailers, e.g., bigger farm as well as specialist food outlets, or those located outside the locality, readable via online food retailing. Besides serving as an essential aspect of consumer society, food-shopping provides a useful base for consumption/production in the agro-food product sector.[178]

GRP involves the risk categorisation of retail food establishments, which can range between risk type 1 (pre-packaged, non-hazardous foods only), risk type 2 (limited menu involving 1 or 2 menu items), risk type 3 (extensive handling of raw materials specific to a variety of process requiring cold & hot holding of potentially hazardous food), risk type 4 (extensive handling of raw ingredient to advance preparation of next day service), and risk type 5 (extensive handling of raw ingredients specific to food processing at the retail level).[179] GRP crucially aims to maintain the required level of food safety, particularly in the food retail industry/sector. This is understood to happen through the following categories: a) certification and training of managers; b) cleaning and sanitation practices; c) food storage conditions; and d) temperature and time controls .[179] Considering the food retail establishments/units, there are operational activities that (field) experience/research identified capable of producing incidence and severity of foodborne pathogens. These activities include those: a) related to sourcing (food from unsafe sources); b) related to processing (inadequate cooking, improper holding time/temperature); and c) related to cross-contamination (contaminated equipment; poor personal hygiene).[179] In typical meat and related retail unit, the GRP would cover eight key areas, namely: a) receiving the meat product; b) storage of meat product; c) fabrication of meat retail facility; d) ground type of meat product and its aspects; e) sausage type of meat product and its aspects; f) processing of the meat product; g) packaging of the meat product, and h) displays of the meat product on the shelf. Each of these areas can constitute some sub-sections, e.g., receiving the meat product can include approved labelling/packaging, meat product inspection, sanitation/pest control. Storage aspects can also seen as another example, which can include storage condition/temperature, box placement, shelf life, cooler and freezer facilities, etc.[179]

From Table 2, GRP (and related) studies investigated sanitation quality of food retail chains/stores [172,173]specific like pork retail outlet, [139] food service workers in retail food establishments, [134,135] and handwashing service industry, [137] which reported various outcomes. To assess the retail foodservice industry's compliance with handwashing regulations, Strohbehn et al. [137] identified some questions that may well arise from the handwashing activities, that is, when hands should have been washed, when hands were washed and how hands were washed. Apart from the differences in the overall compliance with food code recommendation for the frequency in handwashing during production, process service, as well as the corresponding cleaning phases, these workers proposed a benchmark for the number of times hand-washing should be carried out by each foodservice sector during each operational phase. Jame Wyatt and Guy [136] used a sanitation profile scoring form as well as microbiological analysis to evaluate the sanitation of food retail stores in Oregon USA. Whilst certain deficiencies were shown in the sanitation profile, the measurement of sanitary conditions appeared consistent and objective. However, there appeared no correlation between the microbiological quality of products processed at retail stores and total sanitary profile scores. Neal, Binkley, and Henroid [135] investigated the behaviour of foodservice workers within retail food establishments at Houston-Texas and deduced both management commitment and worker food safety were two important behaviour factors for developing a food safety culture. Creating a work environment that encouraged good food safety behaviour/culture could help to reduce the risk of a foodborne disease outbreak. Allwood et al. [134] investigated how food establishment workers in Minnesota were compliant with handwashing procedures. Whilst roughly half (52%) of persons-in-charge could describe the food code handwashing procedure, a bit less (48%) could demonstrate code-compliant handwashing. Besides, a significant association existed between correct handwashing demonstration, physical infrastructure for handwashing and training methods. To improve handwashing practices among the studied (retail) food workers would require interventions that addressed both knowledge of handwashing procedures/requirement as well as development/implementation of effective hand washing training methods. Kungu et al. [139] assessed hygiene practices of pork retail outlets in Kampala district, Uganda, and found over half of pork retail outlets were not authorised to perform slaughtering because meat inspection was not carried out. However, there was a significant association between good hygiene and the presence of public health certificates. Possessing public health certificates was considered an important predictor of good (retail) practice. Picha, Skořepa, and Navrátil [138] assessed the strategic orientation on regional and local products in food retail. The orientation on local and regional products were found the strongest factor that differentiated customers of food retail chain from another elsewhere, which explained about 41% of the variance. Other differentiating factors would include environmentally friendly production sales as well as the quality of food.

Good transport practice (GTP)

GTP involves practical procedures that ensure these are the proper organization, implementation, and control of food products' transport from the producer to the final user.[42] GTP is strictly dedicated to the transport of designated/marked for food use only. Further, the bulk food transported in containers should be reserved for food transport unless the HACCP principles deemed the dedicated transport below the required food safety level. GTP also involves documentation records, e.g., cleaning certificates, food transportation unit number, previous load registration, and temperature/time recordings.[179] All food transportation salvage/spoilage must be handled using the appropriate standards, e.g., itemising/discarding all potentially hazardous food items, food products compromised by the integrity of the package, chemical contamination, etc. All the food products salvaged for human consumption warrant approval by the regulatory authority prior to resale.[179]

The design of GTP considers not only if the food is ready for consumption but also if the conditions for (food product) transportation would introduce, support, or increase hazard at the loading, during transportation, or unloading stages. The adherence to the GTP by the food industry helps to reduce the potential (food product) transportation hazards.[179] The GTP hazards can be categorised, like: a) hazards related to the food transportation unit, for example, the unsuitability of construction material as well as residues from/of previous cargoes and cleaning/sanitising materials; b) hazards related to loading and unloading, for example, food product transportation temperature increases/decreases as well as the undesirable introduction of microbes or other forms of (physical) contamination; and c) hazards (directly) related to transport, which can include temperature control malfunction and leakages of cooling/heating fluid(s).[179]

The GTP ensures the food products that require prerequisite temperature control are those transported without any compromise to food safety. Refrigerated foods require 4°C or less, and throughout the trip, vehicles should be capable of maintaining the temperature range of between – 1 and 4°C. When temperature errors emerge, food product manufacturers must be notified, so as to initiate the special handling procedures, applicable to frozen foods that require minus 18°C or less to preserve (food) quality safely.[179] Proper loading and adequate air circulation must therefore be prioritised, to prevent certain sections of the load attain to a higher temperature compared to the air supplied or returned to the refrigeration unit. This is why the regular monitoring of the air temperature within the (temperature-controlled) transportation unit remains very vital. For the sake of food quality safety, long-distance transportation particularly those of over four hours require documentation using either electronic and or written temperature records within the transportation unit, which thus warrants that the inspection strategy has to be readily available.[179]

The construct and design of a food transport unit should be in such a way that it can eliminate any accessibility constraints, especially in preventing insect infestation, facilitating inspection procedures/processes, providing the appropriate temperature control levels, and reducing cross-contamination.[179] Only the non-toxic and inert (inner) surface materials deemed suitable for direct contact with food should be recommended, e.g., stainless steel or surface(s) coated with food-grade epoxy resins. To reduce contamination risks, the accessories, connections, cleaning/disinfecting and maintenance of food transportation units should be conducted routinely and recorded. All disinfection and rinsing, for example, should be consistent with the manufacturer's instruction.[179] Considering transportation container sanitation, apart from traceability and temperature control, there is international guidance (US-based) related to food safety in the transportation processes, which include International Food Standards via Codex Alimentarius, the US FDA, The Sanitary Food Transportation Act of 1990, and The Food Safety Modernisation Act (FSMA). Besides, to assure quality in food safety transportation, the concepts of internal/external audits as well as continuous improvement should be prioritised.[180] In addition, system management and record keeping are among the key essentials of GTP. Specifically, system management in the GTP context of food safety would consider costs of food safety (and its classification), set of management goals/targets to be achieved, ensure that transit temperature is in control, as well as adherence to tarmac time targets.[180] Moreover, the HACCP plays a vital role in the GTP, especially in preventive control and its (GTP) implementation. Preliminary HACCP plans in the GTP context would involve food safety transportation goals, considering elements like HACCP support team, training, identification of hazards, CCPs, monitoring procedures, corrective action, implementation of standards, documentation/record processes, etc.[180]

From Table 2, GTP studies investigated food commodities transportation/holding [148] and fresh/frozen food transportation, [147] which reported various outcomes. Regarding food transportation safety and by characterising both controls and risks through the help of experts, Ackerley, Sertkaya, and Lange [148] obtained five food safety hazards across the modes of transport, which were considered of greatest concern based on the frequency and severity risk rankings. They included the following: a) lack of security; b) improper holding practices for food products awaiting inspection; c) improper temperature control; d) cross-contamination and e) improper loading practices, conditions, or equipment. Raw seafood, raw meat and poultry, refrigerated raw and RTE foods were found to hold the highest overall risk (in descending order) across all modes of transit. On the other hand, Balzan et al.[147] by investigating cold chain and consumers' practices, reported that whilst the food safety knowledge appears fairly at a good level, the consumer practices were deemed not so appropriate particularly with respect to the transport from store to home, as well as from storage to thaw. In addition, consumers were also particularly concerned that frozen food should not be thawed during transportation.

Hazards analysis and critical control points (HACCP): From fundamentals to categorisation

Introducing HACCP

As a QA-based platform, HACCP aims to meet up with customer expectations, appropriate product specifications, and food safety requirements. It flow-charts the production process, which necessitates HACCP plans consistent with Codex guidelines.[181] According to the Hygiene Rules 93/43/EEC for European food production and based on FAO/WHO Codex Alimentarius, HACCP globally asserts itself as systematic food safety assurance method used to identify, evaluate and control food safety risks.[47,150,156,182] The design of HACCP should be such to identify either the specific processes/steps and or the processing requirements that eliminate, prevent, or reduce an identified hazard to an appropriate/acceptable level.[183] Simplifying the HACCP system to a convenient level may facilitate its integration into the processing systems. As such, the traditional processors could therefore be incorporated using the rather simple techniques, for example, operation time, use of pH strips, and visual examination, so as to assure the product safety.[97] In addition, HACCP's monitoring and verification phases can include the conditions surrounding the thermal processing of canned foodstuffs and other kill steps such as cooking, baking, or sterilising.[183]

Guarantees of HACCP

HACCP guarantees food safety through the adherence of cost-effective preventive and systematic measures.[20] HACCP connects with epidemiological data from surveillance to risk assessment of foodborne disease [102] and most effective to guarantee consumer safety such that foodstuffs will neither be contaminated nor polluted within the supply chain.[33] Given the complexity of food recipes/menu, a flexible HACCP system would suit food operators/services better.[127] By drawing up hygiene codes of practice, applying HACCP principles help identify hygiene risks across food producers.[154] In UAE for instance, the government drives HACCP through four key elements, namely: a) government commitment and leadership; b) appropriate enforcement of legislation; c) food safety risks and strategies to encourage and facilitate the implementation of HACCP via training.-[176] Apart from the HACCP system assuring more structured surveillance over-determined hazards, the corrective actions require a multidisciplinary approach, involving the control of records, documentation, and personal responsibility. When non-conformities in the agro-food product industry are discovered, apart from enabling traceability, the HACCP system facilitates rapid response to changes and enables continuous checks to confirm efficiency.[68]

Developing a plan/team in a HACCP system

Certain criteria must be met within the HACCP system to ensure the adequacy of HACCP plan, [184] which would involve hazard analysis, determination of critical control points (CCPs), critical limit, monitoring procedures, corrective action, verification procedure and documentation.[149] The required stages/steps of developing a promising HACCP plan are presented in Table 3. Herein, HACCP principles can be seen as workable activities, that is, what is involved, what should be described, what should be developed/verified, as well as what should be conducted, determined and established. To produce a robust HACCP system requires assembling the HACCP team, description of the food, and its distribution as well as intended use and consumers, prior to its evaluation and revision.[183] The success of developing, installing, monitoring, and verifying a progressive HACCP

Table 3: The required stages/steps of developing a HACCP plan, modified from Benne and Steed.[183]

Steps	Remark(s) of each step
1. Assemble the HACCP team	It can include five, seven or probably more persons from different operational units of food industry.
2. Describe the food and its distribution	It can involve what is the intention of sale, and how it will be preserved.
3. Describe the intended use and consumers	What are the risks of abuse and misuse?
4. Develop a flow diagram of the HACCP activities/processes	The diagram should be schematic. It should also include (some) pertinent details about the process.
5. Verify the flow diagram	In the verification process, the activities should be consistent with adherence to prescribed (HACCP) contents/practice
6. Conduct a hazard analysis	Identify with the ingredients, packaging and processes
7. Determine the critical control points (CCPs)	Identify with the few food safety points
8. Establish the critical limits to CCPs	It must be science based and measurable
9. Establish the monitoring procedures	It must indicate who checks and how frequent the check has to be carried out
10. Establish corrective actions	It will include activities of how to fix, hold, notify and dispose
11. Establish verification procedures	It will include who conducts the checks and countersigns
12. Establish record keeping and documentation procedures	It will include all documents such as manuals and log books
13. Evaluate and revise the HACCP system	Checking through the various stages for consistency and coherency.

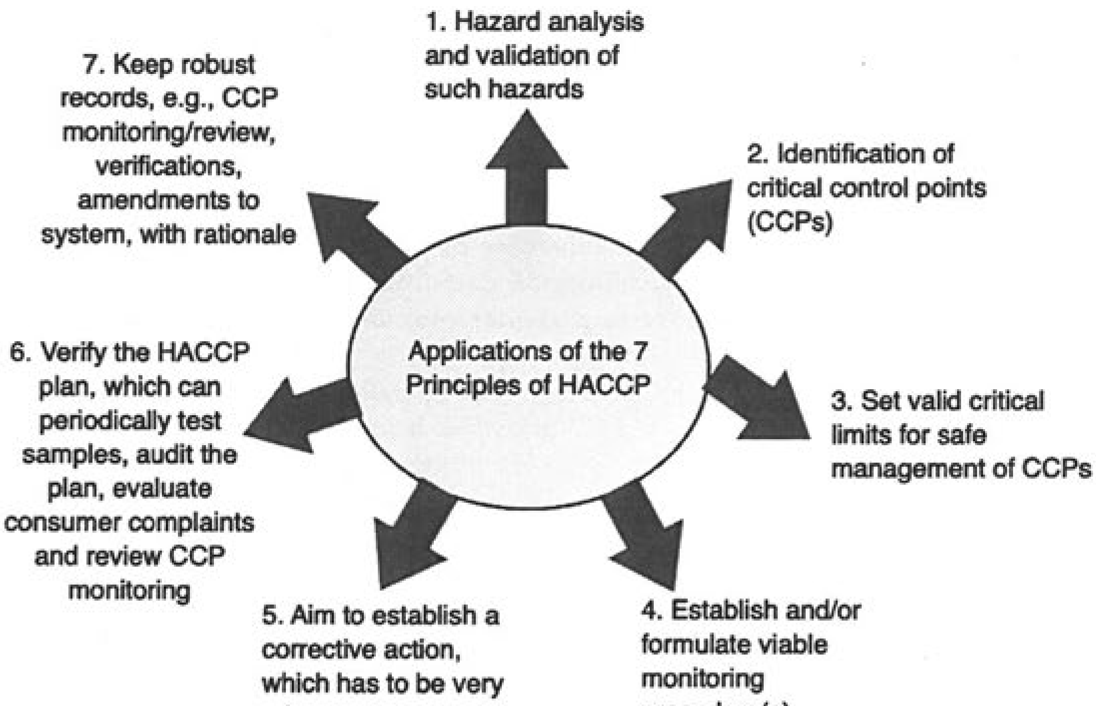

Figure 5. The seven (7) major applications of HACCP principles (Source: Aruoma [23] with slight modifications [permission from Elsevier Science])

system depends on how complex the interaction of managerial, organisational, and technical hurdles are likely to be. As large food establishments see HACCP challenges as difficult, the small and medium enterprises (SMEs) would definitely see it as potentially insurmountable.[185,186] Whilst developing a (HACCP) plan may take time, the emerging (HACCP) system may be in place for several decades.-[155] Indeed, the HACCP plan enhances the food industry's capacity to systematically design programs that implement the microbiological safety of foods.[187]

HACCP: From principles to implementation

The seven major applications of HACCP principles are shown in Fig. 5, which are seven in number, enumerated as follows: a) assessing/identifying threats and possible hazard occurrences and determining control measures as well as counteracting methods of threats; b) determining critical control points (CCPs) so as to minimise hazard occurrence; c) identifying with the established critical limits for CCPs; d) determining/implementing CCPs monitoring systems; e) establishing corrective actions if CCPs do not fulfil needed requirements; f) establishing verification procedures so to verify the effectiveness of the system, as well as if it works according to plan; and g) elaborating and maintaining HACCP system documentation, specific to determining/implementing method of data registration/storage as well as archiving of documentation system.[23,43] Clearly, the HACCP involves the procedures that guarantee the food safety of (food) establishments, by assessing the threat(s) from both health quality and food product viewpoints, added to the hazard risks that could potentially arise within the food production stages.[23] In addition, identifying CCPs refers to knowing the critical point between safety and insecurity, that is, food is considered safe only when critical points are controlled within a safe range. Hazard analysis evaluates CCPs, from point of purchase, loading, storing, transport, sorting, and processing, for example.[188]

HACCP assessment verifies if food distributor/manufacturer can respectively distribute or produce safe food products. Effective implementation of HACCP requires food manufacturers to implement verification procedures, systematic assessment of all food preparation/production stages, controlling as well as identifying with all pathways critical to (food) safety.[26] The competences as well as qualifications of workers remain among the challenges that confront the HACCP implementation process, especially within the food safety system. Some trainers that provide the HACCP training, do so without considering both depths (which areas/concepts and to what extent that needs to be taught), and scope (what had to be taught/what need not have been taught) of coverage. Some managers possess a limited understanding of the global food strategy, as should be required within the food industry. Given the high reliance on a certificate rather than on the competence, food operations should be seen to seek highly motivated food hygiene managers to develop, who would strive to maintain and sustain a robust food safety culture.[154] In addition, the effective implementation of HACCP can play a role in minimising food product recall, arising from contamination.[102] Nonetheless, HACCP in food safety management will become effective only if the personnel responsible for its implementation have the required knowledge and expertise.[23] Besides human resource management being essential to the HACCP system, [68] implementing the HACCP plan/systems would ensure food safety within the agro-food product industry actually works, especially through the (food) process control functions.[181] Given its(over) reliance on the qualitative aspect of the hazard (analysis) and its control mechanisms, the acceptance as well as the application of HACCP in a given food establishment has continually been confronted with limitations.[187] In addition, small food retail mostly encounters a wide range of challenges in HACCP implementation/plans.[189]

Previously conducted HACCP (implementation) studies

Summary of previous studies that investigated HACCP implementation across different agro-food products and related sectors with respective (HACCP) emphasis/focus is shown in Table 4. Sectors that were reported with HACCP implementation, include foodservice operation/industry, [195,208,210] ice cream factory, [199] local food industry, [97,196] food business/enterprise [185,192,200,203,204,212,213] and small and/or medium food enterprise/industry.[193,201,205,209] The processing industries/plants of meat, [191,194,202,206] fish, [197] poultry, [198] and dairy [211] sectors, as well as school foodservice [207] were also investigated. HACCP (implementation) focus includes its commitment to/level of/interpretation, [193,209,212] effectiveness, [97] procedures and practices, [207] difficulties and barriers, [185,201] adding its impact on food safety control process, [211] microbiological quality/outcomes, [191,196,199] as well as usefulness to foodservice operations.[210] Other HACCP focus included

Table 4:Summary of previous studies that investigated HACCP implementation across different agro-food product and related sectors with respective (HACCP) emphasis/focus

References	agro-food product supply chain and related sector	HACCP implementation objective of study	HACCP emphasis/focus
Trafiałek and Kolanowski [190]	Food businesses in Poland	To examine the effectiveness of functioning of HACCP principles in certified and non-certified food businesses in Poland	HACCP impact on food business industry sector
Tomasevic, Kuzmanović, Anctelković, Saračević, et al [191]	Meat processing plants and retail facilities in Serbia	To determine the effects of mandatory HACCP implementation in meat processing and retail establishments in Serbia	Microbiological outcome of mat processing plant and retail facilities before and after HACCP implementation
Trafiałek, Lehrke, Lücke, Kołożyn-Krajewska, and Janssen [192]	Food enterprises at Germany and Poland	To study HACCP implementation at Germany and Polish food enterprises	HACCP implementation according to define 12 steps of Codex Alimentarius Commission
Dzwolak [193]	Small food industries in Poland	To show how small and /or less developed food businesses in Poland have implemented some elements of the HACCP system	How HACCP is interpreted in Poland and main solutions to help HACCP implementation in some small Polish food businesses
Baek, Kang, and Lee [194]	Meat processing plants in South Korea	To investigate the problem and benefits associated with HACCP implementation on livestock product plants in South Korea	Implementing HACCP on accredited meat processing plants
Shih and Wang [195]	Catering food operations in hospital	To investigate the potential factors that may influence implementation of HACCP systems in hospital catering operations in Taiwan	Satisfaction, difficulties, and benefits related to HACCP implementation
Kokkinakis, Kokkinaki, Kyriakidis, Markaki, et al. [196]	Local food industries in Crete, Greece	To survey microbial changes that followed in the HACCP implementation in local food industries in Crete, Greece	Changes in microbiological quality of locally produced/packaged food (ice cream, sandwich etc) after HACCP implementation
Lupin, Parin and Zugarramurdi [197]	Fish processing plants in some Latin American countries	To demonstrate techno-economic merits of applying HACCP with focus on quality cost methodology in fish processing plants in some Latin American countries	Quality costs before and after HACCP implementation, highlighting problems and resultant benefits
Kök [198]	Poultry industry in Turkey	To determine the extent of HACCP (and ISO 22000) implementation in the Turkish poultry industry	Impact of HACCP (and ISO 22000) implementation on poultry meat producers, comparing small-medium and large firms
Kokkinakis, Fragkiadakis, Ioakeimidi, Giankoulof, et al. [199]	Ice cream factory in Greece	To screen microbiological quality of ice cream and safety of production after HACCP implementation	HACCP impact on microbiological quality and product safety of ice cream
Semos and Kontogeorgos [200]	Food industry in Greece	To report the perceptions of costs and benefits of HACCP implementation for the food industry in Greece	Some aspects, e.g., benefits derived of HACCP implementation and operation in food industries
Baş, Yüksel, and Çavuşoğlu [185]	Range of food businesses in Turkey	To determine the barriers of HACCP (and food safety program) implementation in food businesses in Turkey	Barriers, challenges and difficulties encountered in HACCP implementation
Celaya, Zabala, Pérez, Medina, et al. [201]	Food industries in autonomous communities of Madrid, Spain	To evaluate the HACCP implementation in small food industries at autonomous communities of Madrid, Spain	Important barriers about HACCP implementation
Amoa-Awua et al. [97]	Semi-commercial kenkey production plant in Ghana	To apply HACCP (and GMP) to traditional food processing at a semi-commercial kenkey production plant in Ghana	To assess the effectiveness of HACCP (with GMP) by monitoring the environment and kenkey production, as well as auditing and verification of HACCP
Khatri and Collins [202]	Meat industry in Australia	To determine the impact of HACCP implementation of meat industry in Australia	Motivators, constraints, costs and benefits of HACCP implementation

(*Continued*)

Table 4 (Continued).

References	agro-food product supply chain and related sector	HACCP implementation objective of study	HACCP emphasis/focus
Bai, Ma, Yang, Zhao, et al. [203]	Food enterprises in China	To survey HACCP implementation across food enterprises in China	Key aspects, incentives and rewards of HACCP implementation
Baş, Ersun, and Kivanç [204]	Food businesses in Turkey	To determine food safety practices and procedures related to HACCP (and prerequisite programs) implementation in food businesses in Turkey	Knowledge base, food safety practices, and (prerequisite program) challenges encountered in HACCP implementation
Fielding, Ellis, Beveridge and Peters [205]	Small medium food manufacturing enterprises in UK	To evaluate HACCP implementation levels/status n across small and medium enterprises (SMEs) in UK food manufacturing sector	Levels of understanding of hazards and risks in SMEs within HACCP implementation
Maldonado, Henson, Caswell, Leos, et al. [206]	Meat industry of Mexico	To determine the levels of HACCP implementation, costs of implementation and operation, and benefits of implementation for the Mexican meat industry	Cost-benefit analysis and associated aspects of HACCP implementation
Youn and Sneed, [207]	School foodservice in Iowa, USA	To determine food safety procedures/ practices related to HACCP (and prerequisite program) implementation in school foodservice in Iowa, USA	HACCP implementation impact on food certification levels, food safety procedures, and employee responsibilities
Worsfold and Griffith [208]	Catering industry in Wales, UK	To evaluate caterers' perceptions of HACCP (and hygiene) in food businesses/services in Wales, UK	Caterers' perception of HACCP training; To design, deliver and evaluate HACCP training courses for caterers
Walker, Pritchard and Forsythe[209]	Small and medium sized food businesses in UK	To quantitatively assess HACCP (and prerequisite programme) implementation across small and medium sized food businesses in UK	HACCP implementation outcomes in terms of level of commitment, as well as time, temperature and cross contamination controls
Nam, Kim, and Lee [210]	Food service industry in Daegu, South Korea	To determine the effects of HACCP implementation on foodservice industry operation in Daegu, South Korea	Impact of HACCP implementation on some foodservice operations
Henson and Holt [211]	Dairy processing sector in the UK	To explore the incentives that motivate the adoption of food safety controls through HACCP implementation in UK dairy processing sector	Food safety control processes of HACCP implementation adoption in businesses/firms
Panisello, Quantick and Knowles [212]	Food industry in Yorkshire and Humberside regions of UK	To survey HACCP implementation of food industry in Yorkshire and Humberside regions of UK	To establish parameters that affect/ influence HACCP implementation, information about industry's hazard awareness as well as barriers to (HACCP) implementation
Ehiri, Morris and McEwen [213]	Food business operators in Glasgow, UK	To survey the HACCP implementation, whether the information is reaching its target, among food business/ operators specifically in Glasgow, UK	Knowledge of, attitudes to and opinions about HACCP strategy (as introduced into Food Safety (General Food Hygiene) Regulation of 1995)

understanding hazards and risks, [205] quality costs before and after its implementation, [197] caterer's perception during its implementation/training, [208] establishing motivators/satisfaction, difficulties/constraints, costs/benefits during its implementation, [195,202,206] as well as its overall outcome[190,192,194,198].

Youn and Sneed [207] reported the HACCP implementation rate of 22% in foodservice in schools at Iowa schools, which had about two-thirds of directors with a food safety certificate. Having an employee primarily responsible for food safety could increase the chances of HACCP implementation. Shih and Wang [195] reported differences in age, gender, and job position as factors that could influence HACCP implementation in the catering unit of Taiwanese hospitals. The catering staff largely agreed that HACCP would improve the hospital's catering. Worsfold and Griffith [208] indicated that whilst the performance/reaction of caterers on the HACCP free training course was good, the understanding of hazard risks and risk management was low. Indeed, the short-/long-term evaluation may help in widening the HACCP strategy. Elsewhere, the HACCP manual, description of catering service, hazard analysis worksheet, process packs, as well as instructions and procedures were among practical approaches considered useful to facilitate HACCP implementation.[193]

Amoa-Awua et al. [97] investigated the HACCP implementation at semi-commercial kenkey production plants in Ghana, which studied how hazards, aflatoxins, and enteric pathogens associated with the fermented maize product (kenkey) were managed. Results showed raw materials, products, and processing parameters conformed to the critical limits that ensured food product safety. In addition to the reduced aflatoxin levels, such bacterial pathogens as *Escherichia coli, Staphylococcus aureus, Enterococcus* spp., *Salmonella* spp., *Bacillus cereus*, and *Vibrio cholera* were not detected in any of the finished products. Investigating food business operators in Glasgow, Ehiri, Morris, and McEwen [213] reported about slightly over half (59%) had not heard about HACCP. In that study, slightly over half (67%) indicated they needed assistance to identify hazards, CCPs, and monitoring procedures in the food processes. Across the UK food businesses, Walker, Pritchard, and Forsythe [209] identified temperature control activity as least likely implemented because 60% of them (food businesses) employed domestic refrigerators for common purposes, with only about 40% that used temperature probes. Further, about 65% kept records like temperature logs and delivery notes with no apparent reason. A food industry survey by Panisello, Quantick, and Knowles [212] showed the majority of food companies implemented HACCP although lack of knowledge/expertise, as well as the adequacy of resources, still persisted as challenges. Celaya et al. [201] revealed that whilst food industries would have the capacity to apply strategic plans for HACCP implementation, the small (food industries) ones still have several challenges/hurdles in this regard. Additionally, Baş, Yüskel, and Çavuşoğlu [185] identified the lack of prerequisite food safety programs as a key barrier, followed by the lack of HACCP knowledge that retarded the food safety in (food) businesses in Turkey. Elsewhere, Baş, Ersun, and Kivanç [204] reported that within HACCP – implemented food businesses, proper food safety practices and prerequisite food safety programs were oftentimes not adhered to, attributable to the low level of food hygiene management training, lack of motivation, equipment/facility inadequacies and failure of government (support). Maldonado et al. [206] reported that investment in equipment and microbiological tests of products accounted for most HACCP implementation operational costs. Whilst microbial count reduction remained a major benefit, HACCP implementation had implications for both domestic and international food markets.

Trafiałek et al. [192] considered the HACCP implementation in Poland to comply somewhat amicably with the Codex Alimentarius principles and Regulation (EC) No. 852/2004. Further, Trafiałek and Kolanowski [190] understood that the overall assessment of HACCP principles would appear higher in certified food businesses compared to non-certified ones. Despite the certification and food industry type(s), assessing the HACCP principles' functioning across business groups could appear less. In a similar context, Kokkinakis et al.[196] reported the HACCP system would produce a positive effect on the microbiological quality of emergent/resultant products, even though the systematic differences in the HACCP adoption process between the individual firms still persist. However, it is important to reiterate that the decision to adopt HACCP may actually be dependent on the characteristics of firms, for example, firm size and type of products manufactured.[211] In China for instance, medium-to-large size food enterprises are believed to dominate in the HACCP implementation process, which might actually be responsible for their capacity to produce internationally marketed food products. Further, the improved quality of the food product, the capacity to gain access to the new markets, and increased capacity of the market share still remain among the top incentives that drive China's HACCP implementation processes.[203]

The combination of HACCP and ISO 22000 appears to be receiving increasing attention. This is what Kök [198] observed as large poultry firms in Turkey had employed more stringent schemes, making better use of government services compared to the small-medium counterparts. HACCP implementation, according to Baek, Kang, and Lee, [194] aims to improve hygiene in meat processing plants, customer satisfaction, processing plant image, and (plant workers) understanding of food hygiene. It can, according to Tomasevic et al., [191] provide a strong positive effect on the hygiene production process for a given meat processing establishment. In this context, the pathogenic bacteria like *Enterobacteriaceae* and *Staphylococcus* would be the least of the challenges that would affect the meat handlers. It can also, according to Lupin, Parin, and Zugarramurdi, [197] reduce failure costs, improve (production) quality, and better the knowledge of production control as well as planning in a given fish processing plant. Moreover, HACCP implementation in the meat industry particularly across Australia has been more widespread and significant, reducing customer complaints and improving the hygiene of meat products.[202] Whilst the benefits would include the improvements in the food product and production procedures, Semos and Kontogergos [200] identified staff training and production flexibility as major challenges encountered during HACCP implementation in the food industry in Greece. Fielding et al. [205] reported that a majority of workers SMEs in UK food manufacturing operated hazard analysis-based QM, some still found it challenging to correctly define the hazard or risk, or identify the different hazard types. Other workers like Nam, Kim, and Lee [210] understood that at the post-HACCP implementation stages in a foodservice operation in South Korea, the heated foods brought about increased changes in the microbiological quality, indicative of improved standard levels after cooking and serving stages. However, it was understood that the HACCP implementation may not always influence the microbiological quality/level of foods prepared after heating, compared to the non-heated ones.

Categorising/defining the CCPs in HACCP

Regarding the hazards and preventive measures, categorising CCPs would depend on processing plant stages/steps especially with reference to the production/processing of fresh and frozen food products.[156] This is because, the program protocol that is fundamental to the HACCP, would involve: a) identification of food safety hazards; b) identification of processing approaches that best control hazards; and c) implementation of control plan. It is this control plan, which when implemented, would involve several steps designed to eliminate and or minimise hazard, to eventually bring about CCP levels. For example, if a CCP can control hazards completely, it is designated as CCP-1. If it can control minimise hazards, it is designated as the CCP-2.[156] In addition, HACCP analysis should also identify CCPs associated with packaging, which can involve chemical, microbiological, and structural specifications of packaging materials.[32] In the food plant process system, the HACCP analysis should utilise a flow chart/diagram to point out the CCPs (within the process), the latter to depict the stage(s) where the failure to control would allow for the development of microbiological hazards. Thus, each CCP could help indicate some potential control over the hazard that is being identified.[32] By considering the HACCP principles particularly through the evaluation of microbiological safety, it can then be possible to define the adequacy of the CCPs. This should be conducted at the earliest time, especially when the processing system identifies with the corresponding (agro-food) product.[32] In such scenario, the CCP evaluation would involve raw material and ingredient handling, adequacy of time/temperature and sanitation requirements, prevention of cross-contamination, food handling, and employee hygiene, etc. Such evaluation should also relay the items, potential hazard(s), proper controls/procedures and monitoring systems to be employed at each critical point, as well as the individual/staff accountable for the item.[32]

CCPs can also be identified in the risk assessment of food processing plants, which HACCP plan would help to implement. In fact, the ISO 22000 analysis work sheet can help in determining prerequisite programs (PRPs), which help to differentiate the ISO 22000 and the HACCP. The PRPs therefore, when incorporated, can make the ISO 22000 to become more flexible.[214] For instance, the Polish Law defines the HACCP system as the activities that ensure food safety through the assessment/identification of hazard scale from the viewpoints of health and hazard risks during all food manufacturing/trade phases.[101] In agreement with the Codex Alimentarius documents, the HACCP system (under the Polish law) covers the following actions/procedures: a) identification and assessment of health dangers of food quality and occurrence risks as well as the establishment of control/ counteracting means/methods of (such) dangers; b) specifying critical control points (CCPs) that help eliminate/minimise such dangers; c) establishing parameters/requirements for each CCP that needs to be fulfilled and specifying the tolerance range (critical limits); d) developing/implementing monitoring system of the CCPs; e) specifying the corrective actions especially if the CCPs do not meet the (above-mentioned) requirements/parameters; f) developing the verification procedures that conform the compliance and efficiency of the HACCP system; and g) developing the HACCP system documentation, that is related to the implementation phases, and specifying the system of data registration, storage and filling of system documentation.[101]

Quality assurance (QA) and control systems: Some essentials

QA plays a significant role in the food sector by guaranteeing that all quality obligations like food reliability and safety are met. By establishing the processes and procedures, responsibilities, as well as standard organisational structure, several QA systems, successfully targeted the food industry needs through the HACCP, International Standard Organization (ISO), etc.[20] QA standards procedures must be developed at every stage and documented with detailed protocols that address both operations and processes. In addition, protocols need to be accurately and clearly organised, with the corresponding date and signature of the person that has prepared them.[31] Decades earlier, cleanliness of food unit facilities like packaging, processing, and production were considered in hygiene control/sanitation – an integral part of quality control.[164]

Within the food industry, the QA integrates with food safety to develop a quality safety management system.[215] Quality program in the (agro)food industry should integrate quality/safety requirements of food with a set of clear (and well thought through) objectives that consider the required specific raw materials, production, as well as structure of enterprise.[82,216] By adopting the QA systems, the competitiveness in the market would improve. This, however, may not appear so for the small food enterprises, even in the EU.[38] By adopting multiple-hurdle approaches, which would involve training food handlers to be effective in the postharvest hygiene and implementation, the meat industry not only to control the foodborne pathogens of beef, but also, can help to consolidate the QA procedures/framework.[156] When employed in a given agro-food establishment/unit, the QA systems should permit both application and verification of control measures, which assures the quality and safety of the food product. At each step within the food production line, the QA ensures that safe food adheres to both customer and regulatory requirements.[82] Therefore, in order to secure the most appropriate QA system, governments have a vital role to play, especially to provide policy guidance towards the implementation of the QA.[40]

Quality control involves inspecting, testing, and monitoring associated with the control of raw materials, process and finished products. It further aims to fulfil quality outcomes as well as specifically detect if unacceptable defects/hazards do actually exist in the foods.[38] However, the QA in the agro-food product industry would involve a more extensive scope compared with quality control. Beyond inspection, testing, and monitoring activities, QA would involve additional activities devoted to preventing food safety hazards and quality defects.[82] Further, QA control points (QACP) is among (quality) systems strictly based on the HACCP concept within food production. Whereas HACCP is focused on food safety, QACP is focused on the QA system. Although unique for each food establishment, both HACCP and QACP have to be effectively and robustly introduced *as per* the (respective) processing/production line(s).[47] GMP alone cannot serve as the basis of the QM system, given its standardised guidelines for the safe production of foodstuffs. However, GMP should be very effective if the HACCP team considers (its) control measures.[51]

The assurance of food quality and safety guarantees that the agreed-upon specifications of food products have to be met, and is safe from causing harm.[217] Besides, food safety in the QA domain is considered as obligatory, but not so for QM, given the relationship between food legislation, safety, and quality systems, official inspections, and customer requirements.[47] Similarly, the food manufacturers consider food safety as a prerequisite especially when QA measures are incorporated. Importantly, QA, when applied, would protect the domestic food industry against international competitors.[218] Moreover, the (food) industry-based QM system have involved both food quality and safety standards, usually established for a wide range of (agro)food products.[91] In the UK for example, the BRC defines the common criteria that covers the inspection of food suppliers, usually in coordination with major food retailers. Previously, the food retailer(s) would conduct individual inspections but soon enough realised/understood the cost-effectiveness of joint operations.[26] Indeed, the HACCP requirements can be part of BRC, which provides it considerable emphasis on documentation, personnel as well as process/product control.[26] In addition, the framework of BRC largely ensures that the manufacturers produce safe food products and that at the same time manage quality. In addition, the broad scope of BRC strengthens the connection between consumers and retailers.[26]

Other quality standards associated with agro-food product industry

The ISO quality standards used in agro-food industry

a) Comparing between ISO 9000 and 22,000 quality standards

Focused on quality health/safety, the key objective of ISO is to promote the standardisation of the given production process. Applying the ISO system to a food unit increases the insight(s) about both effectiveness and efficiency, not only in cost savings but also in both customer satisfaction and maintaining improvements.[20,26,183] The ISO 9000 family of quality standards, among the most widely known of the ISO standards, constitutes a variety of QM facets. By guiding and supporting both companies and organisations, the ISO 9000 quality standards utilised can provide tools that are required to ensure the products/services are consistent with the customers' needs, for the continued improvement of the overall organisational quality.[26] With QM as the focus, the ISO 9000 quality standards would apply to the different establishments regardless of branch, product, or service. The ISO 9000 quality system series constitutes the following quality standards: a) ISO 9000 – the basis of QM terminologies and systems; b) ISO 9001 – specifies requirements concerning QM systems; c) ISO 9004 – specifies guidelines for improving an already implemented QM system.[43] In addition, the ISO 9001 encourages the effective use of raw materials, equipment, and resources.[219]

Specifically, ISO 9000 appears to be the more widely used quality standard, which would be applicable to the agro-food establishment/industry). It is based on the following eight principles: a) continuous improvement; b) customer-oriented; c) decision-taking based on facts; d) leadership; e) mutually beneficial cooperation with suppliers; f) personnel involvement; g) process approach; and h) system approach to management.[43] Whilst ISO9000 quality system series is voluntary and comes at a cost to the establishment that embraces it, the greater benefit is the increased concentration/understanding it provides on the quality system.Conceptually, the ISO 9001, for example, would present a cyclic connection, that is, management leadership involvement>process management and control>-process system improvement>quality system support>management leadership involvement.[183] As a system, the QA provides some confidence to the food company's management, as well as the government/national regulatory agencies. Through this, the said (food) company could develop increased capacity to attain the designated (food) quality/safety requirements. For example, ISO 9001: 1994 QA system standard got replaced by ISO9001:2000 QA system standard. Notably, the companies to operate with the QA system should have the prerequisite QA activities incorporated within the QM systems.[82] Notably, the International Featured Standards (IFS) corroborates the ISO9001 but has ample focus on the food safety, HACCP, hygiene, and manufacturing processes, which would be very relevant for today's food industry.[20]

Comparatively, the ISO 22000 standard is more recent than the ISO 9000. Specifically, the ISO 22000 standard unifies the principles of quality systems employed in the (agro)food industry.[43] ISO 22000 standard equally facilitates the (food) establishment's capacity to adopt a food chain approach, so as to develop, implement and improve the effectiveness as well as efficiency of (food) safety management.[26,220,221] Further and in diverse ways, the ISO 22000 as a management standard strengthens not only the HACCP but also the preventive action procedure(s). Whereas the HACCP (which is a requirement of ISO 22000) is designed to prevent food safety hazards, the ISO 22000 standard recognises that as new hazards emerge, new control systems/technologies should be designed to control them. In addition, hazard assessment in ISO 22000 standard helps in determining potential hazards that require specific control measures. Besides, the ISO 22000 can be implemented when combined with ISO9001 and its supporting standards.[26,220,221] Nonetheless, the ISO 22000 standard remains firm and robust among the Food Assurance Systems (FAS) with a vertical feed to retail as well as global geographical scope, serving the public interest. With consumer participation as key, the ISO 22000 appears as a de-centralised management system largely driven through the supply chain partnership.[91] An example of ISO 22000 standard is the ISO 22000:2005, which has been associated with how the food establishments should control the food safety hazards with a robust competitive advantage.[26,222] Although optional and beyond the framework of GHP/GMP/HACCP requirements, the ISO 22000 range/scope essentially covers the following: (a) range of such prerequisite programs as GHP, GMP, GAP, GVP (Good Veterinarian Practice), Good Kitchen Practice (GKP), GCP, GPP (Good Production Practice), GDP (Good Distribution Practice) and GTP (Good Trading Practice); (b) HACCP system; (c) Identification/Traceability system; as well as (d) QM system ISO 9001. Clearly, the design of ISO 22000 and by integrating both HACCP and QM, allows for an effective food quality/ safety system, which if implemented can bring about increases in product quality gains/profits.[43,47]

b) Acquisition and status of ISO 9001 and 22000 certificates/certification in agro-food sector

In recent decades, the ISO 9001 certification has occupied useful space within the agro-food industry/ sector. The process to achieve either ISO9001 or 22000 certification is well known to be extremely tedious as well as rigorous. That alone scares off many low capital/small-scale aspects of the agro-food sector. A schematic flow showing some basic auditing stages to attain ISO9001/22000 certification, from intention to apply, through the audit processes, to issuance of certificate/certification is shown in Fig. 6. From this, we can see that the agro-food sector has to think very hard as to whether obtain, for example, the ISO9001 certification. The intention to acquire quality certification like ISO 9001 should not be for the sake of "obtaining a certificate" and the expectation to acquire greater benefits,[26] but should be more on consolidating quality improvement and consumer confidence to the quality of agro-food functions, products, services, and processes. Remember that ISO 9001 operates at a global/ international level. How the auditing process is carried out should not differ much for ISO9001 certification to be obtained in Brazil or Taiwan. The same basic process shown in Fig. 6 should still apply regardless of country, it is still the same ISO9001 certification. Conde et al. [223] noted that ISO certification could positively influence companies' level of internationalization, and these workers could ascertain this when they investigated Spanish agri-food companies. The general consensus of these workers was that internationalization remained a key success factor in the competitive business environment that surrounds the agro-food industry/sector. According to Feng et al., [224] the effects of ISO 9001:2000 quality system certification could have on the operational and business performance of (agro-food) manufacturing and service organizations must not be underestimated. It has been shown that such effects could be positive and significant, especially the use of certification practices (the implementation process, organizational commitment, and subsequent planning) that relates to the operational performance.

Similar to ISO 9001:2015 that leads the globe in QM standards to assure consistency in product quality improvement, regardless of the field of activity, and size of the company, [225] the ISO 22000, management system is also among the favored certifications of the agro-food industry. At the international level, ISO 22000 helps to unify the standards between food chains across different countries, and this is through the issuance of certificates. For example, as of 2014 more than 30,000 ISO certificates are believed to have been issued worldwide.[226] By 2019, based on the ISO survey that showed evidence as per country and number of sectors, the evidence shows slight differences between

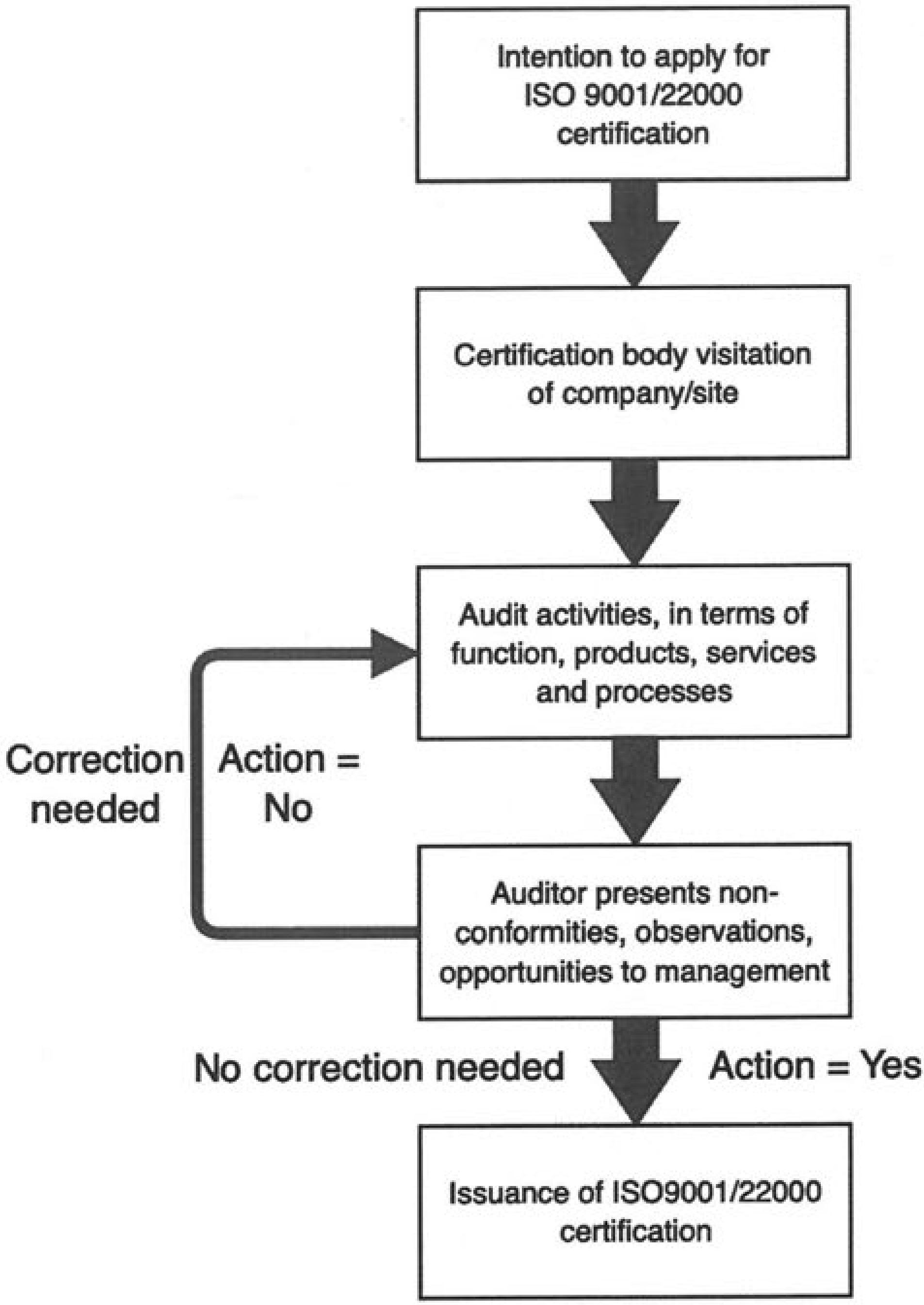

Figure 6. A schematic flow showing some basic auditing stages to attain ISO9001/22000 certification, from intention to apply, through the audit processes, to issuance of certificate/certification.

the number of certificates and sites. For instance, in some countries, the number of ISO certificates is slightly more than the sites, and vice versa. Considering both ISO9001 and ISO22000, China respectively leads with total number of 280,386/281,713 certificates and 12,144/12,426 sites. Globally, the total number of ISO9001 certificates and sites show 883,521 and 1,217,972, respectively. Globally also, the total number of ISO 22000 certificates and sites shows 33,502 and 39,651, respectively.[227]

Nonetheless, the process to acquire either ISO9001 or ISO22000 certification should not differ. Weyandt et al. [228] understood that the implementation strategies for ISO9001 and or ISO22000 certification in companies could be carried out either of these three ways, that is, separately, simultaneously or combined, that is, separately (1 standard), and simultaneously (2 standards). These workers also established that the required time to implement one or more of ISO9001/ ISO22000 certification could range between 15– 32 months. These workers were also able to establish the critical factors underscoring the implementation of the ISO9001/ ISO22000 certification, which can include: a) The empowerment and valuing of people; b) Industry sensitivity towards the implantation of the management system; and c) Interpretation of the (quality-oriented management) standards. Notably, Escanciano and Santos-Vijande [229] identified some reasons for implementing and certifying ISO 22000, which included: a) Improving efficiency, internal processes/procedures, productivity and product quality and safety; b) Anticipating future market trends, strengthening the firm's competitive advantage, and improving the firm's image in the market; c) Customer demands and pressure, increasing market share, and gaining access to foreign markets; d) Complementing HACCP and other management systems, as well as reduce the need for customer audits. These workers also identified constraints confronting the implementation and certification of ISO 22000, which included: a) Not a prerequisite for doing business; b) Unfamiliar to consumers and customers, and of high cost; c) Not required by the government or public agencies; d) The need to hire specialized personnel; e) Paucity of information; f) Insufficient financial aid; g) Seems only interesting for exporters; and h) May not guarantee the total safety of the final product.

Halal and kosher quality safety standards within agro-food product industry

a) Halal quality safety standards

Globally, the Islamic consumers, in particular, comply with the halal criteria/standards and this phenomenon appears to be on the rise, considering the rapidly increasing food market.[230] Halal laws define food products either 'permitted' as halal, 'prohibited' as 'haram' or detestable/questionable as 'makrooh'. The law deals with the following five issues, all but the first associate with the animal kingdom: a) prohibition of intoxicants, that is, all that intoxicates, e.g., alcohol drinks; b) prohibited animals, e.g., pigs, boars, and swine, as well as some seafood, e.g., amphibians; c) prohibition of blood; d) method of blessing/slaughtering; as well as, e) prohibition of carrion.[231] Halal has specific peculiarities with cooking, food processing, and sanitation. Despite that alcohol is prohibited, there seem to be no restrictions on cooking. All halal and haram materials must be separated with respect to facilities, food preparation, etc. Non-halal facilities must be cleaned using halal prescribed methods.[231]

Halal requirements entail both criteria and legislation perspectives, where the food product must comply with: a) not containing elements not allowed by Islamic law; b) not in contact with (Islamic) prohibited substances during production, transportation, and storage; c) neither stored in facilities/ premises nor transported using vehicles that are not permitted. Across all foods, it is the meat that is most strictly regulated in Islam.[230,232] From the EU legislative standpoint, however, no national (public) law stipulates a product has to be halal. However, the CAC has provided the general guidelines for halal food products with some room for minor differences in opinion. Whilst the halal legislation for animal slaughter would vary among countries, the labelling protects (halal) trademarks, to prevent producers from using the (halal) logo for non-halal products.[230]

Halal food supply chain, its integrity from farm to fork, can be seen in Fig. 7. Clearly, the process can be seen to involve the permitted foods and materials, ingredients, and processing, as well as packaging materials from agricultural inputs to consumers' stages. The range covered by both traceability and tracking of the halal status can also be seen.[233] In addition, the halal standards facilitate the certification process and customers' choice that complies with the food products. From the global standpoint, there are a number of halal organisations. For example, the World Halal Council (established in Thailand) that oversee over 40 halal certifications from different countries.[230] To meet the current demands of the (food) industry/sector, the Global Halal Management System (GHMS) attends to the food products, as well as its processes, with an increasingly detailed/robust framework/ system that covers five facets, namely: a) Halal Fundamental Requirements; b) Quality Management System; c) Food Safety Assurance Plans; d) Corporate Social Responsibility; and e) Environmental

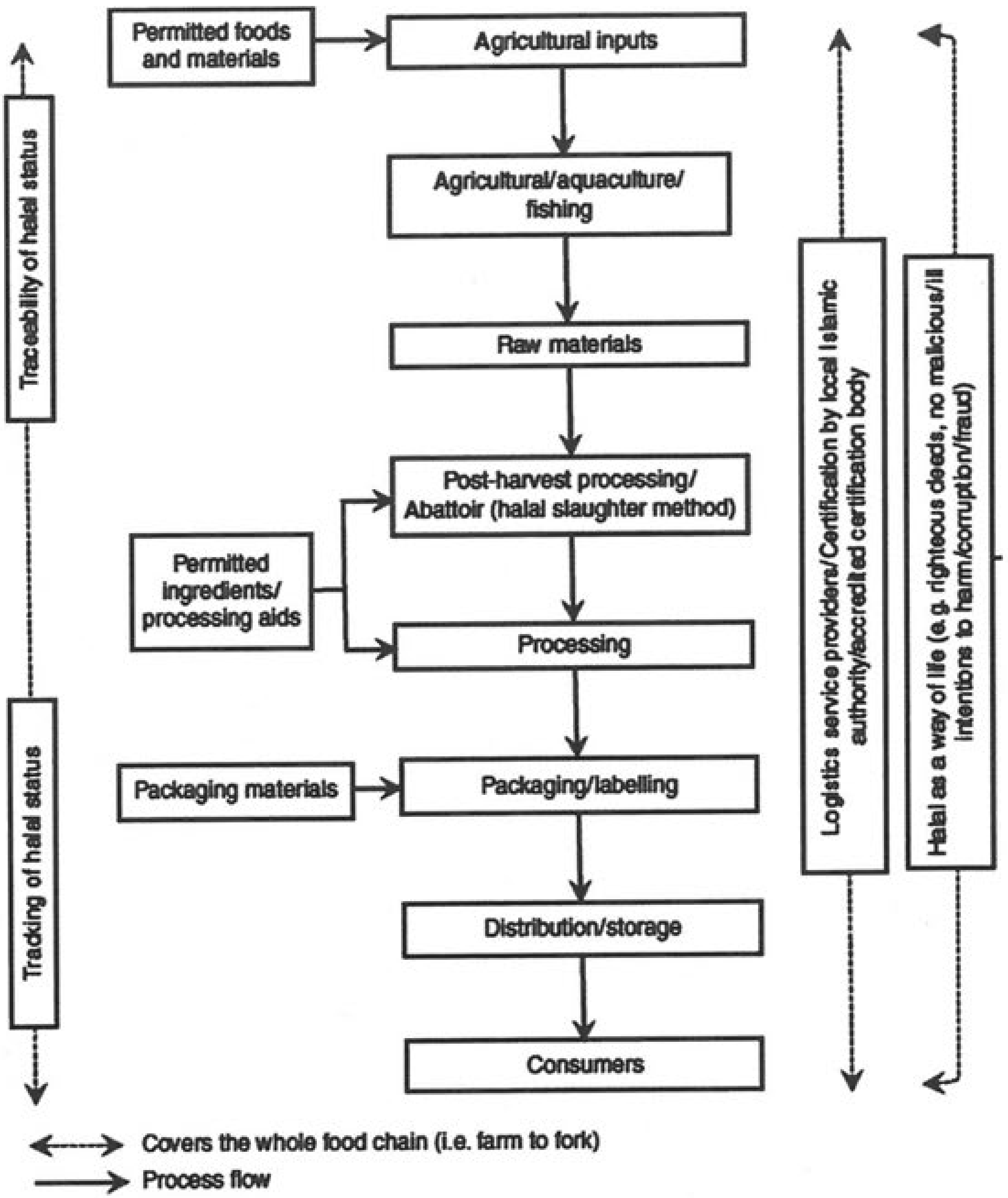

Figure 7. Halal food supply chain, its integrity from farm to fork (Source: Soon, Chandia & Regenstein [233] with permission from Emerald Insight Press)

Management and Sustainability van der Spiegel et al..[230] Gaining more grounds for example in Europe, there is the Muslim Food Board and Halal Food Authority both in the UK, as well as the Halal Food Council of Europe in Belgium.[230] Considering that food supply appears more often than not, no longer produced locally, halal continues to grow, and recent times becoming a global mega-trend food supply platform, even in developing countries.[92]

b) Kosher quality safety standards

Particularly among the Jewish communities, the Kosher dietary laws define the foods as 'fit' or 'proper' for consumption. This principle applies to a wide range of marketed food products. Predominantly, its certification deals with three issues about animal foods, which include: a) distinction between allowed and forbidden animals; b) prohibition of blood consumption; and c) prohibition of mixing 'meaty' 'dairy' and 'neutral' food.[231,234] What makes the food equipment 'Kosher' depends largely on the prior production history. For instance, within the Kosher-focused food industry, dealing with the day-to-day Kosher activities continues to pose challenges, given the diverse nature of (Kosher) supervision agencies, which constitute three broad/major categories, namely:(a) large organisations that dominate supervision of larger food companies; (b) individual rabbis, generally associated with 'Hassidic' communities often with special food brands; and (c) individual rabbis who are more 'lenient' than mainstream standard, able to cut out some of the stricter market standards.[235]

The Kosher food law and its certification have a primary focus, which has always been on both consumer protection and product compliance. It is based on this fundamental principle that the consumers' reliance and trust are invited on the Kosher (food law) and its (designated) product. In 1881, the first Kosher food law was enacted and this was in New York-USA. This 1881 law was legislatively amended in 1922 to make it a more comprehensive law. This New York Kosher food law/statute appears to be the model for all the subsequent food legislation. The enforcement of the Kosher food legislation has varied largely owed to variances in (Kosher's) interpretation.[236,237] The kosher certification of food products is granted by competent individuals or organisations. Importantly, it is the power vested on this competent individuals/organisations that provide the juridical/legal basis to determine that the product enjoys the kosher status.[236] In line with this, as the Kosher certification largely presupposes the inspection of item production serves as a verification of its (Kosher) status, wherein the standards guide the restrictions on the raw materials, production, as well as packaging. Among others, the (certification) process is by choice of the Kosher certification agencies, labelling product system, application of corporate information/manufacturing location, initial inspection, review of ingredients as well as (main) inspection/certification.[236] Besides, Kosher consumers have developed a trademarked labelling system on the food packages to identify the responsible party for providing (Kosher) certification.[92] In addition, Kosher prescribes a wide range of specific requirements for certain food products such as grape products, cheese products, milk products, as well as grain products. Observant Jews apply specific food standards to early fruits and Passover.[231,235] Similarly at the Passover, they avoid eating the usual products made from five prohibited grains, namely wheat, rye, oats, barley, and spelled. In addition, there are periodic recalls of specific products owed to the various kosher defects that would prevent its use, which continually justifies the making of Kosher of any food product as a legal claim 1 at the US Code of Federal Regulations.[231,235]

Factors influencing implementing quality assurance within the food industry/sector

A number of quality assurance schemes/systems abound within the global food industry/sector. The ability of any given food enterprise to adopt a quality assurance scheme/system in order to improve their competitiveness and productivity within its national or even global market remains dependent on a number of factors, which will be enumerated below:

a) *Cost to achieve quality*: Indeed, quality assurance comes at a cost, hence, the concept of 'cost of quality'. According to Bendell et al., [238] cost of quality provides unifying approach to drive quality improvement, and offers basis to identify and prioritise projects in such a manner that it is understood by all. Westgard and Barry [239] illustrated the cost of quality in terms of costs of conformance and costs of nonconformance to customer requirements, depicted in Fig. 8. Both Bendell et al [238] and Westgard and Barry [239] agree that quality costs entail appraisal, prevention, internal and external failure costs. In reality, quality costs require that the given organization's ability to identify the opportunities that need to be prioritised, and subsequently actioned. Small companies find it hard to implement QAS compared to the large ones, largely due to their small size and limited resources.[38,241,242] Moreover, the costs required to either introduce or systematize QAS can be very diverse.[38] For instance, the degree of the bottlenecks that small companies would encounter at adopting as well as implementing a QAS reflects on the cost per worker of implementingfor example, ISO 9000/ISO22000, multiplied by five when its size decreases by a factor of ten.[38,53]

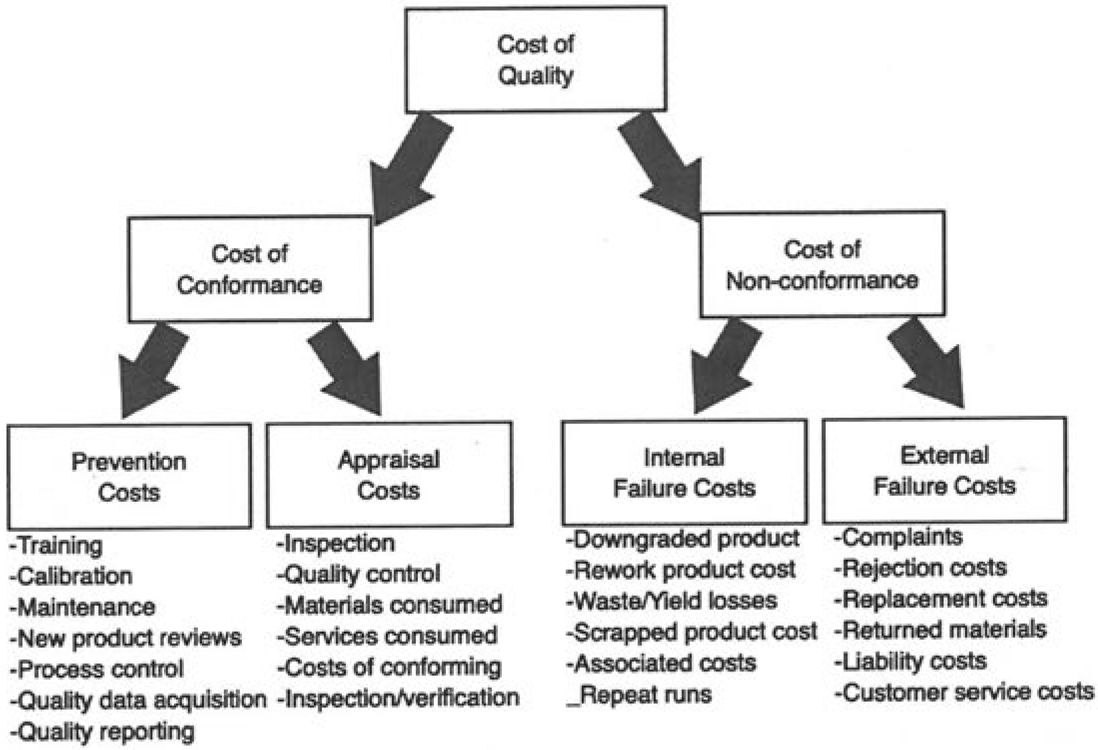

Figure 8. A schematic flow of cost of quality in terms of costs of conformance and costs of nonconformance in meeting up to customer requirements (Sources: Early [240]; Westgard & Barry [239])

b) Lack of quality manager, appropriate personnel and quality unit: Implementing quality assurance requires having the personnel that is fortified with skills to manage and lead the quality unit. Indeed, small enterprises could lack the appropriate/qualified personnel that is needed to implement such a system.[38] To see how lack of quality manager can make impact, we reiterate from Fig. 8, to see again the components of appraisal, prevention, internal and external failure costs, and its associated quality concerns, in order to reflect on how it eventually cuts across starting from calibration, acquisition, inspection, repeat runs, returned materials, to customer service costs. Certainly, if there is no quality manager, the cost to achieve a higher and a very market competitive quality product will go up substantially. According to Karipidis et al.,[38] when professional quality manager is absent in a small enterprise, it creates the need to hire an external consultant. How will the small enterprise know the right external consultant to hire? Moreover, the small enterprise may not even have the (internal) business credentials and skills to ascertain, evaluate, and eventually select the appropriate (external) consultants.

c) Lack of appropriate quality documentation/record-keeping: For quality to thrive in any given food company/industry, the QMS documentation has to be adequate and sufficient. Early [240] identified that there must be a quality manual that comprise job descriptions, procedures and work instructions. The training documents could also be part of the work instructions, and all put together form the quality records. Further to this, when there is paucity of record-keeping, it becomes difficult to know what records need to be kept, what they should look like, how they should be authorised/coded, how long they should be kept, as well as which ones should be disposed off and when. Document control is very core in QMS, and there should be a register for this within the company. Besides, some other workers[38,53,243] have opined that the importance of documentation appears not well understood, even by those who lead small enterprises. Besides, the large nature and volume of documentation that QMS requires could also be daunting, and discouraging, [38,240,244] *d) Lack of financial resources, which impedes human/personnel acquisition*: Financial and human resources work hand-in-hand. The more the financial resources, the more the capacity to elevate the human and personnel resources.[38,238,240]

e) *Lack of quality culture, team and leadership*: The objectives of quality is achievable only through the creating the right-quality culture, as well as quality leadership. According to Early, [240] culture for quality improvement can be actualised through commitment and leadership from the management. The main source of commitment and leadership has to come from the chief executive, who must have the vision of quality and responsible to initiate the quality culture and improvement. Adair [245] proposed a team model for action-centered leadership, which involves an interaction of task, team and individual. Belbin [246] identified that, when building teams, the selection of team leaders is vital to ensure team dynamics produces higher probability of success.

f) Causes of discouragement: There are a number of causes of discouragement that have been considered relevant, which could influence the implementation of QA system in the food industry/sector as identified by several workers.[38,241,247–251] These causes of discouragement could be included as external or internal barriers. They include: (i) employees/managers having difficulties to commit themselves and their time to the task at hand. It is important that managers are equipped with the dedication and knowledge required. This will enable them tackle important quality-oriented problems, which would help to drive the improvement process forward; (ii) Inspectors may not have the required/sufficient knowledge; (iii) The inspectors may not be reliable especially if there are commercially oriented, which might make their auditing process questionable; (iv) The available ISO standards tends not to be flexible, and often considered too complicated to understand; (v) The unavailability of the appropriate educational programs/training; (vi) The unavailability of related/relevant reference quality manuals/materials. Sometimes, executives of small enterprises, in the process of adopting and implementing ISO 9000 systems, discover that, after the certification is achieved, another non-certified enterprise gets awarded a contract by client who had required them to be certified.[38,252]

g) Lack of choices, and investments: To assembly quality assurance system in the food industry is a decision, and requires making choice and being ready to invest in it. Especially for small enterprises, these two components could serve as barriers for progressing to achieving total kind of QM. A number of workers [38,253,254] have considered these (that is, decision as well as choice making) in the following: (i) To achieve quality improvement requires a certain degree of efficiency; (ii) Small food enterprises/industries are more likely to face limitations in quality programs requisitions; (iii) The process of making quality decisions as well as relevant choices demands the use of appropriate methodological tools.

h) Nature/type of goods/food product: The nature/type of goods/food product that the (food/food-related) enterprise trades in or produces could pose a wide range of obstacles to implementing quality assurance within the food industry/sector. For instance, we consider a delicate food product. When the quality system gets implemented, there is a higher chance that the number of nonconformities and rejections would be greatly reduced. On the other hand, there could be a food product with specific characteristics like bulk, delicacy, or even seasonality of production. In this scenario, there could be higher inventory costs for bulky agro-food products compared to other products.[38,255,256]

Supplementary quality associations in agro-food product industry

Process control/standardisation and internal (quality) audits

Process control, more demanding than it seems, ranges from planning, controls, and specification, cleaning/waste management, handling, packaging and storage, corrective and preventive actions, to production trials and quality records. For instance, planning could range between short, medium, and long term, or even on a rolling basis but yet can still remain regular.[53] Further, process control is also very essential in (preparing) guidance notes of the agro-food industry because it considers all production stages, from receiving raw materials to the delivery stage of the product. Serving as a key element of ISO9001 contents, a good process (control) would certainly delineate CCPs. The responsibility of process control within the agro-food industry rests with either the factory manager or production manager.[53]

Applicable to the agro-food product industry, the standardisation depicts a management (process) tool that constitutes largely of documentation procedures. Considering that the production line hold various processes, there would be technical criteria/specifics to ensure products, as well as processes, are designed with quality.[257] For instance, process standardisation would focus to minimise the variations in product/production quality. Provisions can therefore be made to ensure that analytical and operational procedures, equipment/facilities, machinery, and raw materials get standardised.[257] Instrumentation patterns demonstrate the goals and procedures aimed to accomplish the work, and classified as follows: a) Standards of Quality – parameters related to the quality of inputs, products, and raw materials; b) Operation Standards – manufacturing processes of products, technical control/ operational parameters; and c) Standards Inspection – criteria/methods to assess the degree of achieved success in delivering activity/work, compared to planned levels of products quality, which can be carried out on either the raw material, finished product or the process itself.[257] Quality outputs can be realised through the wide range of process standardisation, e.g., improved product standardisation/product quality, cost reduction, simplification, and optimisation of production processes. Others include an increase in the technical capacity of process operations, reduction of inventory levels of raw materials/inputs, reducing preparation time of machines, etc.[257]

The internal quality audit program should be a participative type, which ensures that every phase meets up to the prerequisite quality certification standard, especially prior to the arrival of the external standardisation bodies/inspectors as well as their representatives. Essentially, the internal auditors need to undergo a very robust set of preparation/training, which involves quality and quality assurance processes, as well as documentation. In addition, the internal auditors must be guided through the (audit) review processes.[53] For the internal (quality) audit to be successful, it has to be thorough. This is because the internal audit serves as a vehicle that facilitates the constructive improvement of a given organisation. A successful internal audit is clearly a prerequisite in achieving quality certification standards. And for this to be actualised, it would be vital to have: a) an established procedure, that comprises checklist, audit, review, corrective action, and close-out; b) comprehensive training program for auditors; c) frequent/routine internal audit schedule(s); and d) company/establishment awareness of (internal audit) program purpose as well as (auditee) knowledge of the part played.[53] For example, an audit used in the halal production is largely described with the help of prescribed guidelines/standards, e.g., Malaysian Standard ACB-Halal Product. Hence, as certification organisations develop their own audit schemes, many companies employ Muslims to work at production sites to help serve as internal checks. The challenge of halal audit rests on how backward into the food supply chain the auditor has to go before been able to declare a product as 'halal', which would differ, from the acceptance of basic ingredients to the check of each ingredient at any given time.[230]

Benchmarking and harmonisation processes

The benchmarking process (with respect to the agro-food industry) would focus on quality standards.[17] Regardless of the internal or external types, benchmarking can be applied in three ways, namely: a) Process Benchmarking – better understanding about the process, compares performance against internal and external so as to delineate improvement/optimisation strategies; b) Strategic Benchmarking – compares strategies to strengthen planning, to delineate priorities; and c) Performance Benchmarking – collate information about the outcome of quality, and compare them internally/externally.[258] From the QM viewpoint, benchmarking and harmonisation largely work together. Benchmarking is considered 'a process of measuring the performance of a company's processes, products, and services against those of another business, seen to be the best in class'. Benchmarking, therefore, aims to delineate internal pathways for quality improvement.[259]

On the other hand, the harmonisation process (with respect to the agro-food industry) would aim to minimise either the redundancy process or conflicting standards that might have evolved, independently. The major aim of harmonisation is to establish common areas that are critical/essential, so as to attain a unified standard.[260,261] Moreover, the increasing complexity about 'global quality standards' and growth of 'competition/trade' within agro-food sector greatly influence benchmarking and harmonisation, with the associated quality standards like a) Benchmarking for mutual acceptance between different standards; b) Benchmarking of standards to develop an additional checklist; c) Establishing task force for participative and with representative quality standards for benchmarking; d) 'One-way' benchmark, where certain quality standard serves as a basis for benchmarking of another standard; e) Developing main criteria for benchmarking quality standard; f) Coordinating as well as improving audit activities including internal/external audits; and g) Developing new standard with the harmonisation of different standard requirements.[17,262–264]

Traceability in food quality and safety contexts

Widely practiced across various institutions, traceability remains a useful candidate that locates the root cause of particular quality/safety concerns. Regardless of the production stage, the traceability is largely based on products' recorded information.[257] In the agro-food industry, the traceability concept remains very relevant to initiate improvement as well as prevention actions, to deter the emergence or repeat of a specific problem.[257] With respect to food quality, traceability provides a history of production, application, or location of any (food) entity, by means of recorded identification as well as (overall) product distribution.[47,215] With respect to ISO9000 standards, traceability extends to the identification of the origin of materials or parts, the processing history, etc.[215] The

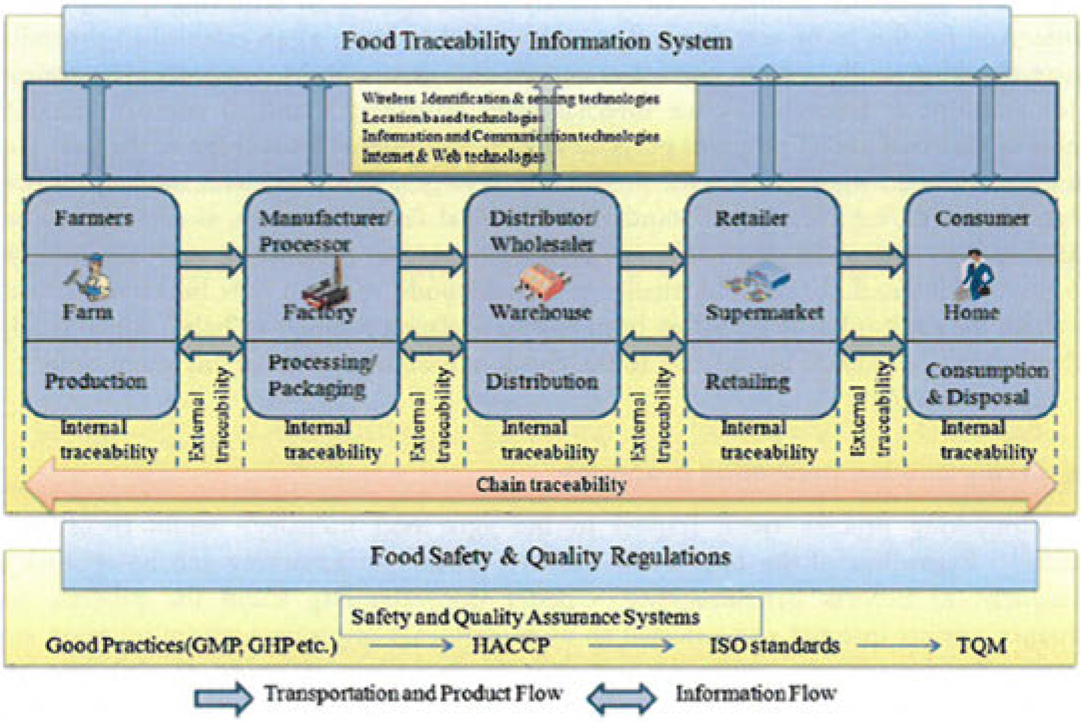

Figure 9. The conceptual framework of the food traceability system. It shows the scope of chain traceability captures internal and external aspects, simultaneously adhering to food safety and quality regulations, which the food industry sustains by engaging good practices, HACCP, ISO standards, which eventually cumulates to the cycle of total quality management (TQM) (Source: Aung & Chang [215] with permission from Elsevier Science).

efficiency in traceability can balance the benefits with the costs, as characterised by three key players, namely, the breadth (i.e., the amount of information collected), depth (i.e., how far back or forward the system tracks the relevant information) and precision (i.e., degree of assurance to pinpoint a particular movement of a food product). Further, traceability tool is key to motivate the need to answer such questions like: 'who' (i.e., actor/product), 'what' (i.e., actor/product information), 'when' (i.e., time), 'where' (i.e., location), and 'why' (i.e., cause/reasons) with regards to food quality, safety, and visibility.[215]

By regulating the compliance of food safety requirements, the traceability process would provide an effective quality safety monitoring system capable of increasing consumer confidence as well as connecting consumers with producers.[215,265,266] Essentially, traceability stands among legal requirements, which when adopted largely targets to improve food safety particularly within the supply chain.[85,267] Although food safety attributes are rarely commented to consumers, traceability continues to be among production processes that firms include, somewhat like a standard safety check within their quality standard platform.[268] Other authors have considered traceability among process indicators that enhance product quality of agro-food products.[269–271] When the traceability of products increases, consumers can rapidly evaluate the food product quality to increase the transparency of the production process.[85,272] Both QA and traceability increasingly top the priorities of food retailers, as the latter continually strive to take extra steps to ensure food safety. Both QA and traceability can be achieved through a consistent yet high quality/robust supplier – involved QA program.[84,273]

The conceptual framework of the food traceability system, is shown in Fig. 9. As an information driven-kind of system, information technology is shown as incorporated to facilitate both internal and external traceability components. In addition, the food safety/quality regulations and quality assurance systems function throughout the chain traceability space, from the farmers' production to the consumption stages.[215] To have a good understanding of traceability regulations/standards, the food industry must have food quality safety standards. From a legal/regulatory standpoint, the exchange of food traceability data is important to achieve a transparent and smooth transfer of information among the food supply chain actors.[215] Further, the documentation procedure as part of the traceability is vital within the food establishments' internal process, which can include: a) external discharge (ED); b) VAT invoice; c) Trade Identification Document (TID); d) Inter-Warehouse Transfers (IWT); e) Internal Dispatches and Deliveries (IDI and IDE).[43] Considering the increasing popularity of food safety (GHP, GMP, HACCP, etc.) and quality (ISO 9000/22000) systems, the traceability systems are very vital especially in tackling the growing consumer concerns associated with food quality and safety challenges.[47]

Besides enhancing the food safety standards, traceability can help the food industry become economically vibrant given its robust tracing system, which is able to identify with the specific sources of problems.[31] For instance, fresh produce traceability (FPT) has documented instructions as developed by the EHI Retail Institute, European Association of Fresh Produce Importers (CIMO), Euro Retailer Produce Working Group (EUREP), European Union of the Fruit and Vegetable Wholesale, Impact and Export Trade (EUCOFEL), Southern Hemisphere Association of Fresh Food Exporters (SHAFFE).[31] To help make traceability more effective/efficient, there is appropriate software under consideration, which could help to ensure the agro-food establishment/firm is effective in managing product quality, particularly in tracing the products' origin as well as quality.[43] In addition, the companies must be attentive to the bar code/number application of registered authorities/framework, so as to enhance the tracing of the fresh produce.[31]

Food inspection process and laws/legislation: Some essentials

a) Food inspection process: Some highlights

Food inspections are aimed to identify quality improvements, for example, in food-related projects. With respect to food quality/safety, inspection requires planning, prior to implementation,

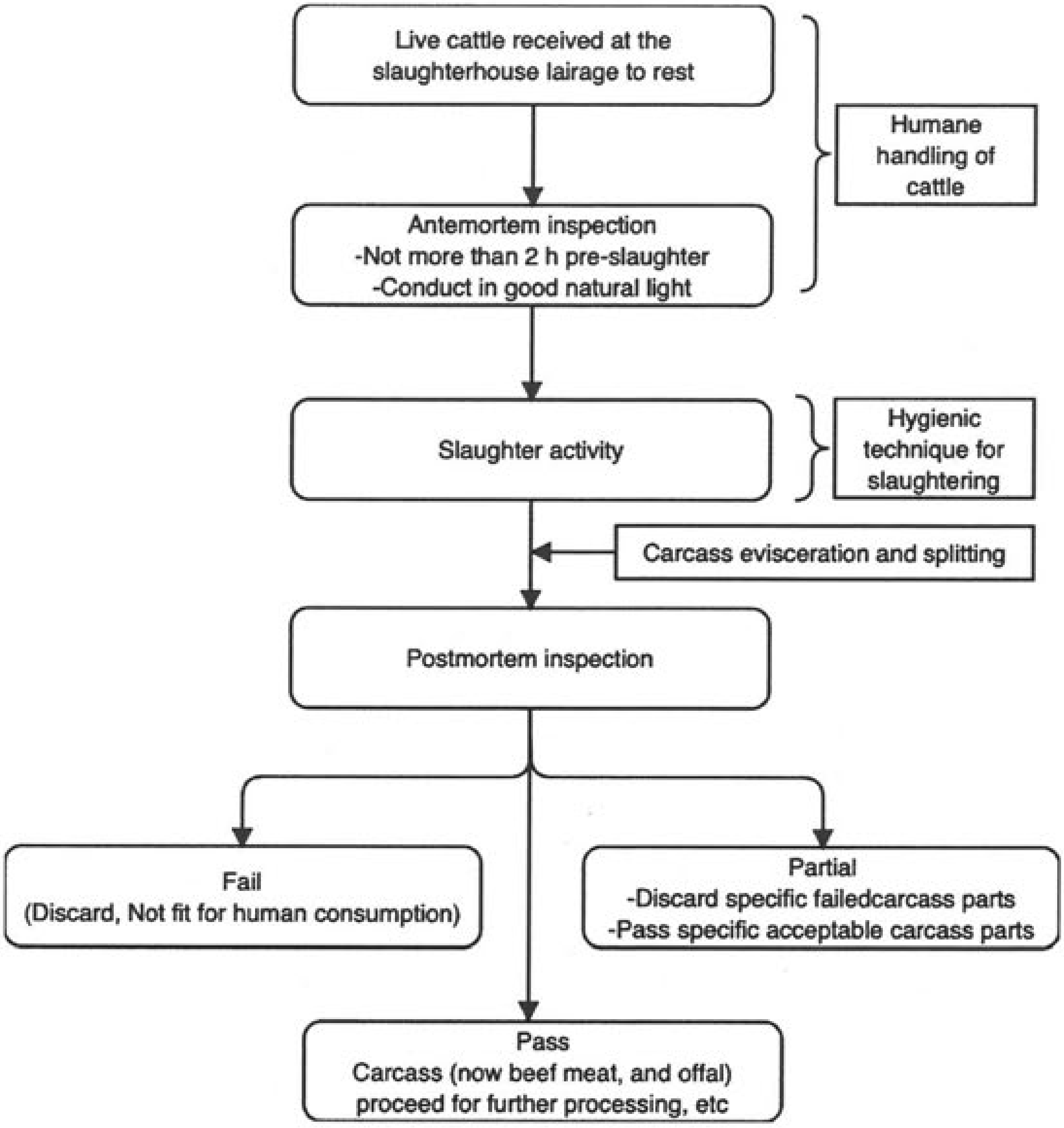

Figure 10. A schematic representation of the basic meat inspection activities involving cattle slaughter in a typical slaughterhouse in Nigeria. The figure shows the humane handling of cattle and hygienic techniques for slaughter before and after antemortem inspection. The postmortem inspection would provide three major outcomes to the eviscerated/split cattle carcass/beef meat, which include either fail, partial, or pass (Source: Okpala, Nwobi & Korzeniowska [275]).

followed by monitoring action/activities – a never-ending cycle of quality improvement, which constitutes a part of (total) quality management.[94] Food inspection should not be confused with an audit. This is because the (food) audit (whether internal/external) aims to certify the manufacturing quality of food products, which largely involves product manufacturing, GMP, product quality, and HACCP.[274] Either official or unofficial, the food inspection remains very crucial as a food quality safety/management machinery. In Nigeria and specific to the meat industry as an example, there is the meat inspection process routines conducted by veterinarians across various slaughterhouses. The meat inspection process itself is a food safety and compulsory QM activity. A schematic diagram of the basic meat inspection process in a typical abattoir/slaughterhouse in Nigeria, which involves the cattle slaughter activity is shown in Fig. 10. The key stages include the assembly of live cattle at the slaughterhouse lairage, to conduct the slaughter process, the evisceration of the carcass, and being split into desired portions, towards preparation for sale/storage.

Herein, the crux of (bovine) meat inspection shows two major well-known facets, which include both antemortem and postmortem aspects.[275]

In Poland for example, the EU and national food laws have provisions that are regulated through the (food) inspection systems, and its implementation is officially supervised by the state inspectors.[47] Notably, the most important aspect of the food inspection, from the consumers' perspective, is the permit to release of the final food product(s).[240] Besides, the food inspection directly associates with QA systems, although the latter is of voluntary implementation. Despite this, the food quality should be subject to the inspection, specifically, to ensure the consistency as well as conformity between the actual product qualities, as declared by the food chain sector.[47,274] In addition, the food inspection appears to occupy a useful space within the ISO standards, particularly in the process management and control.[183]

b) Food laws: Some historic contexts

The rapid urban population growth, public health concerns, and new distribution/innovative food supply chains are among major bottlenecks confronting food production, which brought about the creation of food laws.[160] The 1860 voluntary act for 'Preventing the Adulteration of Food and Drink' in England was the first comprehensive food law. This 1860 voluntary act got replaced by a mandatory act in 1875. Between 1897 and 1971, the Codex Alimentarius Austriacus under the Austro-Hungarian empire developed a collection of standards and product descriptions. Strictly speaking, these (collection of standards), not legally enforceable food standards, lent its name to what it is called today, that is, 'International Codex Alimentarius Commission'.[160] In the USA, the Pure Food and Drugs Act of 1906 became the first major federal consumer law, specific to food processing, which prevented the interstate and foreign commerce of adulterate and misbrand drinks/foods, as well as consumer fraud/poisoning. However, there was a loophole in the Pure Food and Drugs Act of 1906, which in the subsequent years allowed poor quality food products and deceptive packaging to thrive. By 1938, the Food Drug and Cosmetic Act, which replaced the 1906 Act, appears to be a law that provided the foundation for subsequent (food) legislative standards.[160] In the EU, the Directorate-General for Health and Consumer Protection keeps food safety laws up-to-date, properly enforcing it across the member countries.[156] In 2002 for instance, the EU adopted the principles of food safety in a regulation called General Food Law Regulation (EC) No 178/2002, which constituted stringent measures/regulations on the release, marketing, labelling, and traceability of foodstuffs. Besides, the Directorate-General for Health and Consumer Protection depends on the European Food Safety Authority (EFSA) to provide scientific data on food safety. Compared to US counterparts, EU food safety organisations possess more legal authority over (agro)food produce.[156]

Essentially, the EU Food Law involves chemical safety, food contents/ingredients, food product description, hygiene and sanitary conditions, and a number of other (food) product regulation specifications. Notably, EFSA coordinates EU Food Laws. However, every EU nation possesses its own (national) regulatory body.[31] In addition, food laws do have some level of universality, which makes them globally comparable and legally binding. Clearly, food risks in one country would become a burden to all. For example, 1990 Food Safety Act of UK, Public Health Act 851 of Ghana, 1992 Food and Drugs Law of Ghana – all emphasise the illegality to sell unwholesome food, adulterated food, food prepared under unsanitary conditions, and the need for authorised persons with the technical know-how to supervise the food production process.[163] Globally, countries make an effort to update food control laws, combine legislation on food quality and safety with effective programs. Many countries continually propose strategies to confront the challenges mitigating enforcing food laws, via further training of food inspectors, the establishment of research/development support facilities, etc.[25] Food legislations allow authorised persons/companies to check consumer food products and ban them if they do not meet safety requirements.[31]

c) Food legislation and enforcement: Some briefs

EU legislation help ensures food operators are responsible for food hygiene/safety targets to ensure public health/protection. Food law regulations would continue to incorporate HACCP principles.[127] The EFSA established by Regulation No 178/2002 of the European Parliament/Council of Europe laid down general principles/requirements about food law/procedures in matters of food safety.[43] As part of quality control, food law guides food safety programs. For example, such programs like GMP, HACCP, British Retail Consortium (BRC), and Global Food Safety Initiative (GFSI) help enforce food laws within the food industry.[276] Another example worth mentioning is the EFSA published simplified FSMS for certain small food retail establishments. Indeed, developing similar FSMS requires a fundamental understanding of processing activities/stages that have the capacity to increase the occurrence of hazards.[277] This simplified approach can also help in achieving control using PRP effective FSMS activities, which can include critical limits and record keeping, when required.[278]

As enforcement of food laws remains the responsibilities of governments, the implementation of food safety procedures is oftentimes tied up within such food laws, being imposed by (Federal and State) regulatory bodies/frameworks.[84,91] In regulating and sustaining food quality, food laws help to assure consumers that food product purchased is safe and meet their expectations. The food laws, with respect to the principles of distribution/production of raw materials, foodstuffs and its (direct) contact objects, can overlap the set of legal norms. In addition, food laws can be focused towards attaining the level of protecting consumer health as well as fulfilling the food safety expectations.[47,91,279] In foodservice establishments/units, the compliance to food laws (and food safety/industrial practices) can be limited by such factors as absence of effective enforcement/consumer pressure agencies/groups, lack of management interest and motivation as well as lack of resources and technical knowledge.[163]

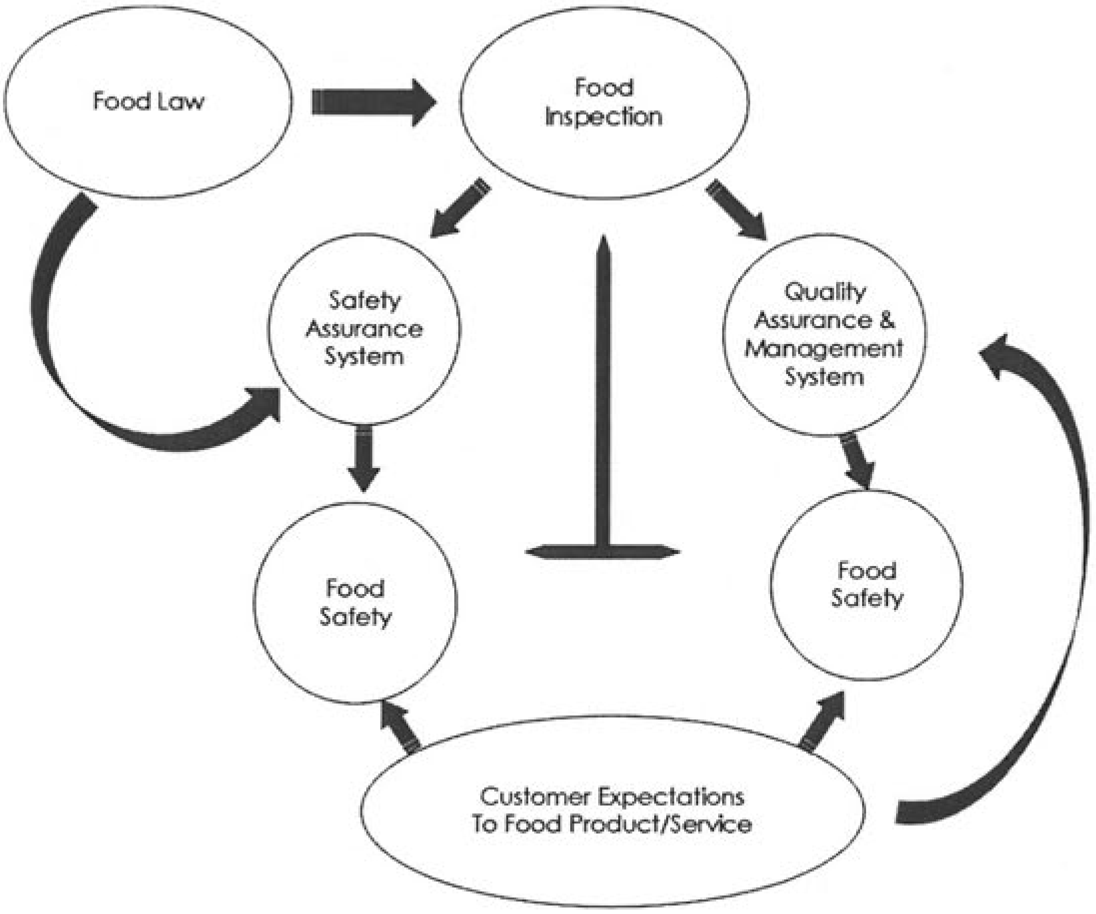

Figure 11. Integrated schematic flow linking food law, food inspection, quality and safety assurance, with consumers' expectations regards to food safety and quality (Source: Sikora & Strada [47]).

d) Integrating food law, inspection with quality safety: Some briefs

Integrated schematic flow linking food law, food inspection, quality, and safety assurance, with consumers' expectations regards to food safety and quality, is displayed in Fig. 11.[47] Here, the food inspection can be seen to directly connect to safety assurance, food quality, and can as well extend to QM. This can point to why the inspectors' role, working within the confines as prescribed by both legal and regulatory frameworks, to implement the food law, is important.[47,274] Fig. 11 also shows that the customers can equally contribute through feedback mechanisms, to improve the food product quality/safety. Ultimately, the feedback mechanism aims to enhance the entire/overall inspection process. Indeed, this mechanism/pathway would provide the platform for inspection officers/agencies to put forward constructive suggestions, which they have delineated from the challenging aspects of (existent) food laws/regulations. Depending on the changes as well as dynamics in the quality/safety implementation processes, it can be presumed that the inspection officers/agencies would proffer their constructive suggestions, which can lead to useful amendments to any challenging aspects of (existent) food laws/regulations. In addition, the implementation of food laws exclusively rests on the safety assurance systems such as GHP, GMP, and HACCP.[47,91,274,279]

Risk assessment in food quality and safety: Fundamentals, levels, phases and scope

Risk assessment involves a systematic process of identifying, organising, and analysing information about risks so as to acquire clarity and consistency in presenting available as well as practical decision-making data. Generally, decisions involving food safety requires defining the risks as well as applying specific regulatory sanitary measures.[83] Largely, risk assessment in Europe is guided by EFSA, which help to communicate food safety topics to support risk managers at the European Commission (EC), European Parliament and EU member states.[189] Although risk assessment can apply to diverse food safety areas, it can be more specific too, e.g., developments that assess risks associated with a particular food product, or food-hazards combined within food safety management systems.[280]

a) Risk assessment in the HACCP concept

As a risk assessment tool, HACCP considers (food) contamination as a whole, whether intentional/unintentional. HACCP approach involves the development of an operational prerequisite program (OPRP), which targets to control the likelihood of introducing food safety hazards and/or

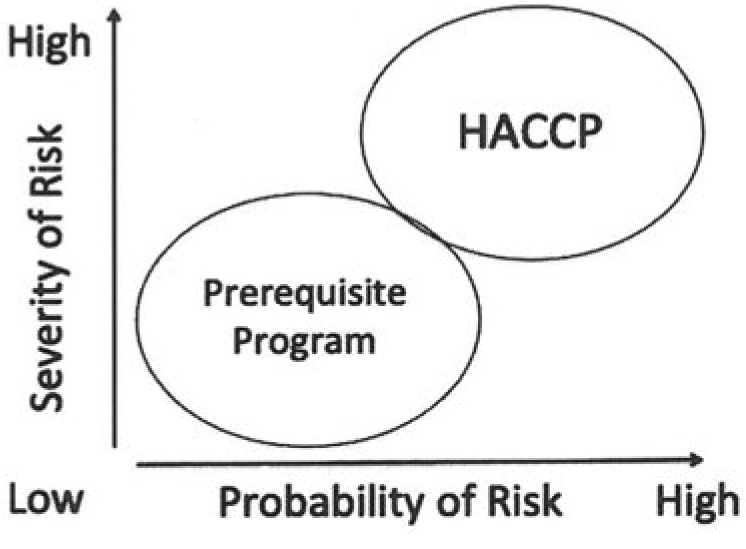

Figure 12. Risk assessment within the HACCP concept, presenting low/high probability and severity levels. Both risks within the prerequisite program and HACCP circles can bring about severe health conditions/situations (Source: Bennet & Steed [183] with slight modifications)

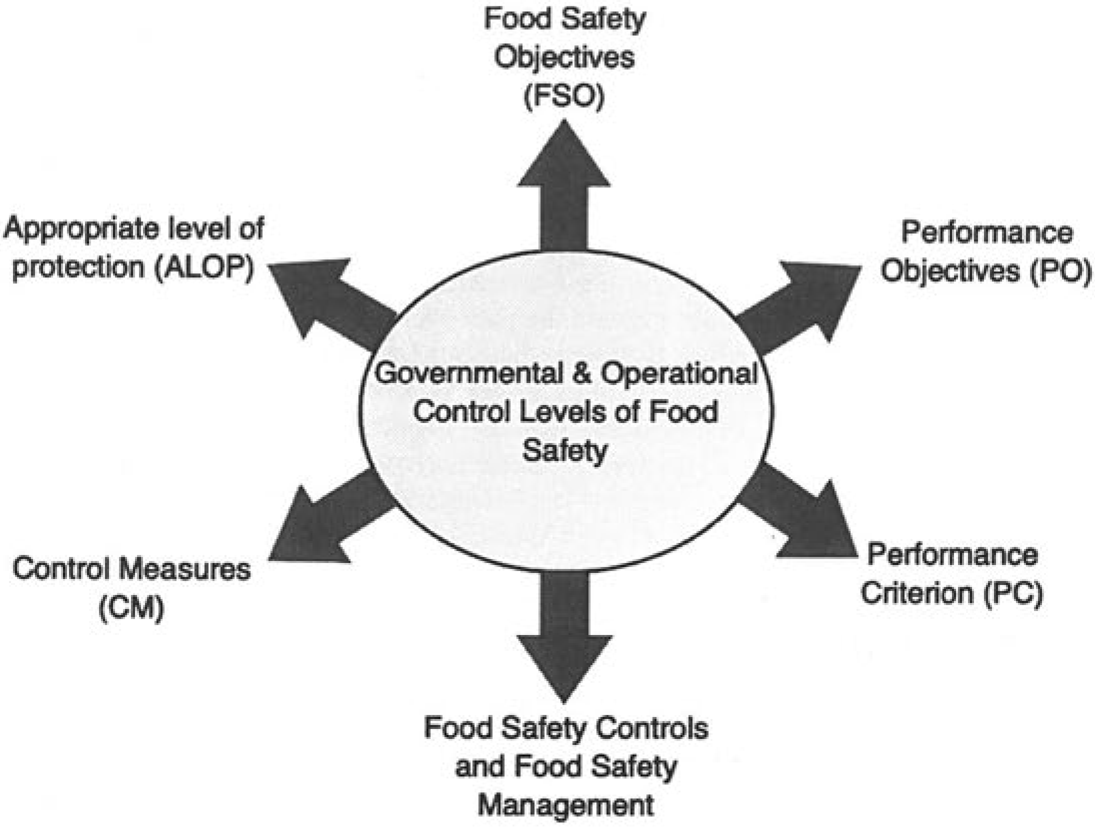

Figure 13. Risk assessment criteria based on food control (Source: Aruoma,,[23] with slight modifications, [permission from Elsevier Science]).

contamination of (products) food safety hazards.[281] Besides, adulteration makes food products fall short of legal standards, which eventually makes them to become unsafe and not wholesome,[282] which points to risk assessment from the HACCP perspective thus very relevant. The risk assessment probability and severity levels associated with the HACCP concept is shown in Fig. 12. Both the low and high probability and severity levels can be seen. Additionally, the prerequisite program(s) and HACCP circles/domains can also be seen. Outside these circled areas within the graphical space is occupied by the greater challenges, which involve biological, chemical, and physical risks.[183] Either the high probability/low severity or low probability/high severity would bring about illness/injury, which makes the evaluation of total preventive systems against any potential hazards highly warranted. For example in a given meat/poultry operation, despite the low chance of probability of a known pathogenic microorganism, the severity could remain very high.[183] Besides, risk assessment has been shown with the capacity to employ the Failure Mode and Effective Analysis (FMEA) model, which allows for the streamline of product development processes, especially from the ethics and legislation perspectives, very much applicable to a variety of food processing plants.[283–285]

b) Risk assessment criteria based on food control

The risk assessment process should provide an estimated impact, as well as the probability of adverse health effects attributable to potentially contaminated foods.[286] The use of HACCP concept/framework together with microbiological risk assessment can help in evaluating the health status of a given population and its corresponding food product as well as product group, which associates with for instance a specific (foodborne) pathogen.[23] The risk assessment also provides an absolute as well as relative indication of risk to a given population, regardless of the origin of the food product. Risk assessment criteria based on food control, is shown in Fig. 13.[23] The terms used in this figure require some explanation. An appropriate level of protection refers to the level of protection deemed appropriate by the member (country) establishing sanitary measures to protect human, animal, or plant life within its territory.[23,176] Food sanitary objective (FSO) can refer to the maximum frequency of hazard in giving foodstuff at the time of consumption, which contributes to the appropriate level of protection (ALOP). FSO remains an option that provides guidance to food safety management, as expected in managing risks.[23] Performance objective (PO) refers to the maximum frequency of hazard in giving foodstuff at a specific stage within the food chain before the time of consumption that contributes/provides to an ALOP/FSO, as applicable.[23] Performance criteria (PC) explain the effects in concentration/frequency of hazard(s) in food(s) that must be achieved by the application of one or more control measures to contribute/provide to PO or FSO.[23] Control measures (CMs) refer to any action/activity employed to either eliminate/prevent food safety hazard or reduce it to an acceptable level, which can include microbiological guidelines/specifications on hygiene codes, microbiological criteria, pathogen control, as well as (other) specific information, e.g. labelling, training, education, etc.[23]

c) Risk assessment as food science-based investigation

By connecting communication with management, risk assessment can involve the initiation of processes, prior to the evaluation of results.[176] Food safety officers inspect food establishments, and this should be a fundamental practice in national food standard agencies. The food safety officers also coordinate with the food business operators, in order to introduce the food safety systems, especially in new premises. The food safety officers are able to carry out these duties given their training in understanding hazards and risk management associated with a variety of food products, production and related processes. The food safety officers have a well-documented roles as well as responsibilities within food safety regulatory framework, which can include: a) inspection with respect to license requirements; b) maintenance of database per food business operation; c) preparation of food safety plans; d) response to incidents related to food poisoning, and e) sample collection for testing.[176] In a given national food system, risk assessment – a food science-based investigation that forms a significant portion of risk analysis framework as shown in Fig. 14, comprises of steps namely: a) hazard identification; b) exposure assessment; c) hazard characterisation; d) risk characterisation; as well as e) scope of risk assessment.[23,176,286,287] We will succinctly mention them subsequently, so to understand what they all entail.

Hazard identification, largely, is considered a preliminary yet qualitative evaluation of analysed information . It equally considers the contexts of both chemical and microbial risk assessment. For instance, the initial action of the microbial risk assessment will determine major exposure sources to the pathogen, or determine which pathogen(s) might be of an issue specific to a given food/food commodity group.[286] *Exposure assessment* estimates the exposure likelihood of an individual/population to microbial hazards. It also considers the microbial load likely ingested, as well as where the unit of exposure typically is per meal portion size. The characteristic of pathogen agent, initial contamination of raw material, level of sanitation/process controls, methods of either distribution, packaging, processing, and or preparation, the microbial ecology of food as well as storage of foods, are among influential factors the risk assessor must consider.[286] *Hazard characterisation* requires understanding how the disease incidence would depend on such factors like attributes of food that alter host/ microbial status, general health/immune status of hosts, number of ingested cells as well as virulence characteristics of the pathogen. As human population response to foodborne pathogen exposure highly varies, any microbial dose–response would consider various modes of pathogenicity associated with different (pathogenic) foodborne bacteria. If the causes of disease were not fully expatiated, the knowing host/food matrix effect/influence on pathogenicity would be difficult.[287] As the final stage in microbial food safety risk assessment, the process of *risk characterisation* is where the exposure and dose–response assessment jointly provide an overall evaluation of the likelihood that the population is likely going to adversely suffer owed to the hazard outcomes. Therefore, the risk characterisation targets to communicate the confidence level that risk assessors have in their analysis. Adding to the overall interpretation of results, the risk characterisation would summarise the impact though critical

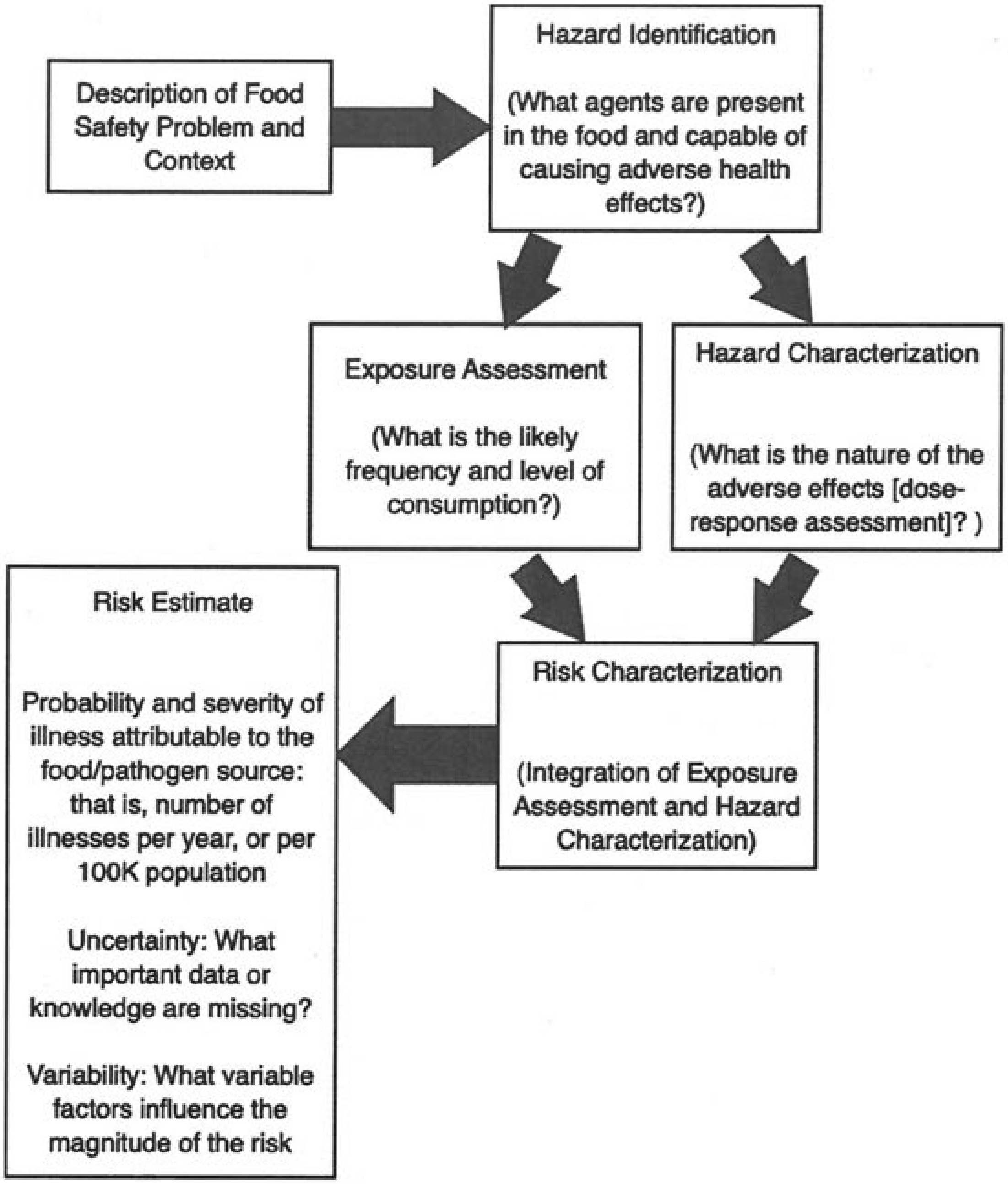

Figure 14. Risk assessment remains a science-based investigation that forms a significant portion of risk analysis framework (Source: Aruoma, [23] with slight modifications, [permission from Elsevier Science])

assumptions, together with decisions of developing the exposure and dose-response would have on interpreting the overall assessments.[287] Additionally, the *scope of risk assessment* depends on the (risk) management question and reason for performing the assessment. The identification source must be authentic, with a clear risk profile description through a food safety problem/context. Through consultations, the assessor(s) and manager(s) must ask the right question(s) that guides the direction/selection of information throughout the risk assessment process, which helps food safety follow both qualitative and quantitative pathways.[286]

Validation and verification processes in food safety

By definition and in the context of food safety, validation refers to the effectiveness of managerial and technological control measures,[37] which considers well designed and systematic method that assures the system performs consistently with the design specifications.[288] Validation helps to determine as well as ensure that the intended result is achieved, which from the HACCP standpoint indicates that hazards are controlled at each CCP.[155] Validation is checked in advance so to attest it is: a) judged in an objective way that requires real data and or independent people; b) specific for food production situations; and c) supported by scientific evidence. Validation can include obtaining evidence about one (or a combination of) control measure(s), and if properly implemented, controls hazards associated with a given specific outcome.[37] From the analytical perspective, validation can interpret whether the analytical purpose of the method is achieved, by obtaining results with an acceptable uncertainty level. Validation in the analytical sense forms the first level of quality assurance in the laboratory and therefore ensures the analytical method is fit for purpose.[289] Ideally, validation is done prior to implementing a valid HACCP plan. Once validated, the food product is considered as fit for purpose, such that CCPs would control identified hazards to make its occurrence become rare.[288] Many information sources used to validate the CCPs help establish critical limits, for example, scientific literature, government regulations, etc. The validation process can end with mandatory/compulsory periodic revalidation of HACCP plans, to confirm its validity.[155] In addition, validation plays a key role in GMP, to ensure that facilities/equipment, processes, test procedures are under control to consistently produce quality outputs.[152] Additionally, the EU and the US within their legislations have adopted procedures for HACCP validation and verification.[154]

Besides continuous auditing and verifying within the HACCP system, there is initial validation and revalidation. Importantly, the individual conducting the food safety audit is not the same determining the corrective actions. This ensures some degree of impartiality.[26] By definition, verification in this specific context would refer to procedures carried out to validate the effectiveness and suitability of the HACCP system.[240] Also, US National Advisory Committee on Microbiological Criteria for Food (NACMCF) defined verification as the use of methods, procedures, or tests in addition to those used in monitoring to determine if HACCP system is in compliance with the HACCP plan and/or whether the HACCP plan needs modification/reevaluation. What is being verified is the HACCP system, what is being validated is the HACCP plan.[155] As a determination of correctness, verification helps to confirm objectively that the evidence about specific requirements has been fulfilled. Similarly, it is applicable to methods-related performance to check for the effectiveness of intervention/preventive facilities, for example, hygiene design, etc.[37,39] It also involves prerequisite programs (PRP) that support HACCP, followed by observations and interviews of people, who calibrate equipment, monitor, and review the CCPs.[26]

Besides confirming that the specific requirements have been met in its entirety, the verification checks after implementation/utilisation of managerial and technological measures if the control activities already put in place have been operating as designed. Further, checking must be done in a reliable/valid way.[37,39] Verification methods/requirements can include: a) routine review of control and monitoring results; b) reviews of the quality of the in-process and final product as determined by product analysis; c) review of results of shelf-life assessments/products; and d) review of customer complaints.[240] As an internal process conducted by the food/industrial plant/regulatory body, the verification process runs continuously with auditing of the HACCP system in adherence to plan and scheduled with the prerequisite framework of regulatory agencies.[155] Verification – applicable to halal products, ensure the food industry meets (halal) food production requirements with prescribed religious criteria, which is usually through a combination of audits and laboratory tests.[230]

Personnel/staff assessment and (further) training

An assessment of staff within the agro-food industry has several phases and would commence when assessors are appointed either internally or externally. Documentation activity help verifies that all aspect of the quality standard is being addressed. Dependent on the QM program and quality certification standard being targeted, assessment should implement the corrective action based on deficiencies (initially) established.[53] From the food safety and quality standpoint, the assessment procedures can feature three potential outcomes, namely: a) Serious deficiencies found, such that certification to the standard cannot be recommended; b) Standard lacking minor details, which leads to recommending a certification to the standard after corrective action; and c) No problems is found, which allows for a complete recommendation of certification to the standard.[53] To attain a successful assessment, a food firm/unit may find the competencies and incorporation of the internal quality lead assessor and verifier useful, particularly to chair the assessment house so as to equip the agro-food unit/establishment with the relevant quality assessment/certification procedures towards the desired standard. Further, the assessment procedures would certainly require adherence to a prescribed/ specific document format. After the certification of the desired standard has been achieved, surveillance visits can then be planned to check management's consistency in sustaining QM standards.[53]

Within a given agro-food establishment, staff should embrace all forms of internal assessment to help measure competencies and strengthen the commitment to the job role. An objective/thorough assessment would enable top management to identify areas where further training of staff is necessary. Bolton [53] reported the great benefits of having the qualified personnel. Importantly, the qualified personnel are able to fulfil the job role and perform adequately within the given agro-food product unit. In addition to identifying the required training needs, the documentation records are expected to outline the staff's experience, qualifications, and training required to execute the job role. Besides, in-house training should cover food hygiene, knowledge of national food safety law/regulations, consistent with the job instructions. Adding that every staff should have a training record, departments should document the assessment of skills capability of staff, together with an annual review of training requirements.[53] Another context that demonstrates the importance of personnel development can be seen in the work of Okpala, Nwobi and Korzeniowska.[112] These workers studied butchers in a typical Nigeria slaughterhouse as it pertains to their knowledge and perception of GHP and GSP. Butchers, besides being very conscious of their knowledge and perception of GHP and GSP, have to strive to continually improve their slaughterhouse services to assure beef quality and consumer safety.

Challenges/Non-conformities encountered during the auditing process of food safety management systems

Implementing FSMS and its certification remains a very crucial strategy that helps ensure food safety in both private and public (food) establishments. The implementation process is necessary to ensure competitiveness and improve quality assurance systems. Food establishments, largely those at the small-scale level, to implement FSMS are confronted with challenges like huge costs and lack of financial power, lack of international market, uncertainty about the potential benefit of FSMS, as well as lack of consumer awareness of FSMS benefits, [290] all of which can influence the auditing process. Broadly, the auditing process in the food industry is divided into internal and external facets. The internal audits involve those conducted by internal auditors that work for the organization. The external audits involve those conducted by a third-party organization.[291] Audits can be grouped based on auditor–auditee relationship, which brings about first-party (self-assessment), the second party (proprietary audits), and third party (conduction of audits by independent auditors that often leads to certification) audit types.[26,292]

Djekic, Tomasevic and Radovanovic [293] investigated the quality and food safety issues associated with certified food companies in three Western Balkans countries via a survey method, which involved analyses of audit reports that specifically targeted nonconformities and/or improvement opportunities from 123 food quality/safety audits across 60 food companies. The QMS audits revealed the management process (21.8%), before control (14.5%), increasingly related to documentation and control of records. Within the (food safety) audits, managing food safety issues (17.5%) and various aspects of food safety control (15.5%) were noted. Besides prerequisite programs including GHP requirements occupying majority of findings (59.6%), the audits would generate twice as much nonconformities compared to those of QMS audits. Kotsanopoulos and Arvanitoyannis [26] similarly concurred that managing and control of food quality /safety were among key concerns that needed attention in the food industry. The auditing process, therefore, has to be specifically geared to assure food safety. By investigating the food supplier qualification, Losito et al. [294] evaluated the auditing system and non-conformances within an Italian large-scale-distributor. In particular, what underpinned their study included the fact that the suppliers for large-scale food distributors were required to meet many specific requirements, and had to undergo audits so as to assure the hygienic and sanitary quality of their (food) products. These workers revealed that the major non-conformances involved "management systems" at higher rate, and that large food plants applied the HACCP principles better compared to the small enterprises. These workers provided an example of a checklist that could detect the non-conformances status of its food suppliers, as well as information on HACCP system management.

Djekic et al. [295] delineated the benefits and constraints associated with improving confectionary industry supply chain through second party audits. Their investigation involved second party audit using a developed quantitative quality/food safety (audit) tool, and the audit program involved flour mills and food packaging producers. Their findings showed that certification status does not necessarily imply high performance of a quality/food safety system. Further, their findings showed that companies could experience challenges in identifying processes, setting performance indicators, as well as implementing problem-solving tools. Additionally, their work considered quality control as essential because there were cases where companies did not document their control methods, and had no method in place to verify the consistency of their results. Overall, the main food safety constraint via the audit was shown to be HACCP implementation. Albersmeier et al. [296] evaluated the reliability of third-party certification in the food chain, which ranged between checklists to risk-oriented auditing. Their work was based on a database analysis of the German certification system Quality and Safety (QS) as well as workshop with the QS-certification bodies that conduct about 85% of all agricultural audits. These workers were able to deduce the first empirical hypotheses regarding what connects the reliability of third-party certification with those of the institutional framing of standards. The premise for their study was that certification is increasingly relevant for agribusiness, and that in Europe, substantial parts of the value chain are already certified by standards like International Food Standard (IFS) or GLOBALGAP (the former EurepGap).

Challenges/Determinants encountered during the implementation of food safety management systems

The determinants of food safety management systems (FSMSs) and their implementation can be market-based, or rather, market-driven.[297] By implementing food safety management systems (FSMSs), it is possible for food companies to respond to real and perceived food safety hazards. For emphasis, the FSMSs are largely public-based like ISO 9001, ISO 22000, Hazard Analysis Critical Control Point (HACCP), as well as industry-based like GlobalGAP, British Retail Consortium (BRC), Safe Quality Food (SQF), International Food Standard (IFS), and Food Safety System Certification (FSSC). Challenges that face the FSMS, especially with respect to implementation, which is also applicable to QMS, underpinned by two factors, internal and external. Internal factors include the perceived economic incentives and disincentives. External factors include the industry and regulatory pressures. These two (internal and external) factors affect the firm, process, and product characteristics.[297] Other useful barriers that hinder the implementation of FSMSs include: a) Lack of willingness by other supply chain partners to participate in the implementation of FSMS; b) Lack of

Table 5 Differentiating ISO9001 and ISO22000 in terms of ownership, standard, adoption scope, global total valid certifications/sites, and global scale

Items	ISO 9001	ISO 22000
1. Ownership	Public	Public
2. Standards	International	International
3. Adoption scope	Across all industry types	Applicable across the food supply chain
4. Global total valid certifications/sites	883,521/1,217,972**	33,502/39,651**
5. Global Scale	Across the continents of the globe	Across the continents of the globe

Source: ISO Survey 2019 [227]; Abebe et al. [297]; ** Based on ISO Survey 2019 data.

clarity about the benefits to be gained from implementing FSMS vis-à-vis required investment costs; c) Lack of trained staff for technical and management aspects of FSMS; d) Expensive and complicated task (i.e., there are economic, technological and legislation constraints); e) Resource-intensive, require much administration and paper works which place a burden on companies; and f) Lack of complete, accurate, timely, and easily accessible information about the need for FSMS.[297]

Karaman, Cobanoglu, Tunalioglu, and Ova [298] identified barriers of implementation of FSMS among Turkish dairy industry like lack of knowledge relating to, as well as cost of HACCP and other food safety programs. These workers suggested that periodic training and consultation services for FSMS applications specific to the dairy industry by the government, together with financial support was needful. Vladimirov [299] analysed the factors of implementing efficient FSMS in food retail sector and food industry in Bulgaria, and found that some infrastructural difficulties as well as perceived negative effects of the the official control were main challenges. Macheka et al. [300] studied the barriers that influence implementation of FSMS in Harare Province, Zimbabwe. These workers identified key barriers such as inadequate facilities and infrastructure, lack of financial resources, lack of top management commitment, as well as size of organisation. Despite these barriers, it was found that the main benefit/motivation to implement FSMS was to increase employee skills, improve company image, and most importantly improve food product quality and safety. Investigating implementation of FSMS in the UK, Mensah and Julien [301] revealed food enterprises claimed that statutory regulations were biased towards consumers without the conduct of adequate impact assessments on all stakeholders within the food supply chain. These workers opined that this bias would cause the food

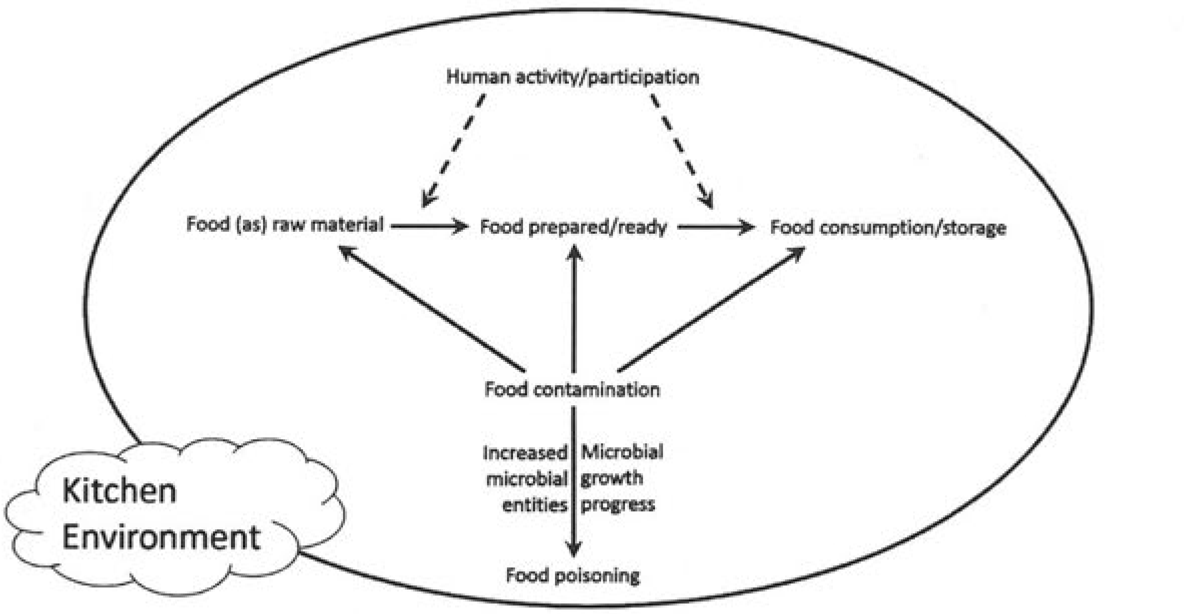

Figure 15. Schematic diagram showing human activity/participation during food (as) raw material, preparation, and consumption stages, adding food contamination that can progress onto poisoning, all within the kitchen environment (Source: Okpala & Ezeonu [29]).

industry to incur significant costs that could others be avoided. Additionally, the cost of non-compliance was considered as significant to enterprises despite that compliance with food safety regulation remained burdensome.

Understanding the extent of FSMS implementation with respect to ISO9001 and ISO22000 requires differentiating the two based on ownership, standards, adoption scope, and their global scale, and this is represented in Table 5. Both ISO9001 and 22000 are public and under the international standard framework (that is, the International Standard Organization). The difference is that, whereas the adoption scope of ISO9001 cuts across all industry types, the ISO22000 is applicable across the food supply chain.[227,297] That is clearly why there are more ISO9001 valid certifications and sites over the ISO22000 ones. Therefore, the domestic market environment would have a role to play in order to connect well with the industry-based FSMSs. This is because the domestic market environment is largely dominated by small (traditional) retailers.[302] Indeed, the industry-based FSMSs appear to be more heterogeneous as well as stringent and thus, entail higher compliance costs.[87,297,303] Another concern is that the FSMS implementation requires a high level of organizational commitment for it to be fruitful.[40,304] Having a QA unit in the food firm can be very useful, and if absent, may hinder FSMS implementation.[305] Equally, the education level of the QA manager can be an obstacle to the full implementation of FSMS in a given food enterprise.[297,305]

Some reflections into the relevance of QM in progressing food hygiene quality safety standards and related processes

Food industries around the globe are increasingly embracing various aspects of QM.[20] On the other hand, consumers continue to remain the ultimate judge of any (food) industry's quality performance.[306] Previous empirical studies we came across that gathered QM practice/performance data have largely been based on firms' perspectives.[8,306–308] Regardless of how mature the QM field is, future studies should incrementally aim to fortify its (QM) definition, which was founded by: a) addressing content via explicit identification of QM level (principles/practice/technique); b) striving for standardisation of definitional terms; and c) testing existent instruments that are able to measure QM practice dimensions.[1]

Good practices have to be part of human activities, which would be found in the activities surrounding food material preparation, and consumption/stages as depicted in Fig. 15. This is what Okpala & Ezeonu[29] believed in their review of food hygiene/microbiological safety in a typical household kitchen. In the home for instance, because the kitchen is where food is largely handled, this concept of food hygiene/microbiological safety should be reflected across other food preparation/production places[29]. This is because food contamination can take place at any stage(s) within the food supply chain, which if it started from the very onset of the chain can increase probability of (food) contamination, and eventually result in worst case scenario of food poisoning. Therefore, it is very important to reiterate herein that food safety and different good practices go together, regardless of human culture, history, and lifestyle. If good practices were analysed in a typical food operation/unit, three categories can emerge: a) Those directly connected with food technology, e.g. GMP; b) Those indirectly connected with food issues, e.g. GRP, GTP; and c) Those that deal with all activities concerning food handling, etc., e.g., GHP.[154] In food processing, the large number of good practices, whether it is GMP, GLP, GAP, GCP, GHP, etc., appears to interconnect with each other. For example, GCP sometimes finds itself embedded in GHP.[166] Besides, competency is a prerequisite in both quality assurance/management and food safety practice. HACCP personnel programs require employees to effectively manage CCPs. HACCP implementation requires highly motivated food hygiene managers who would develop/maintain a food safety culture.[68] In addition, enforcement of kosher standards varies in the Jewish community. Kosher's integrity is very important in the food supply chain.[236,237] Similarly, halal integrity is very important in the food supply chain. Any haram contamination /dishonesty with halal standards remains a great concern to Islamic consumers. This is because the Islamic consumers largely depend on the food industry/policymakers to quality assure

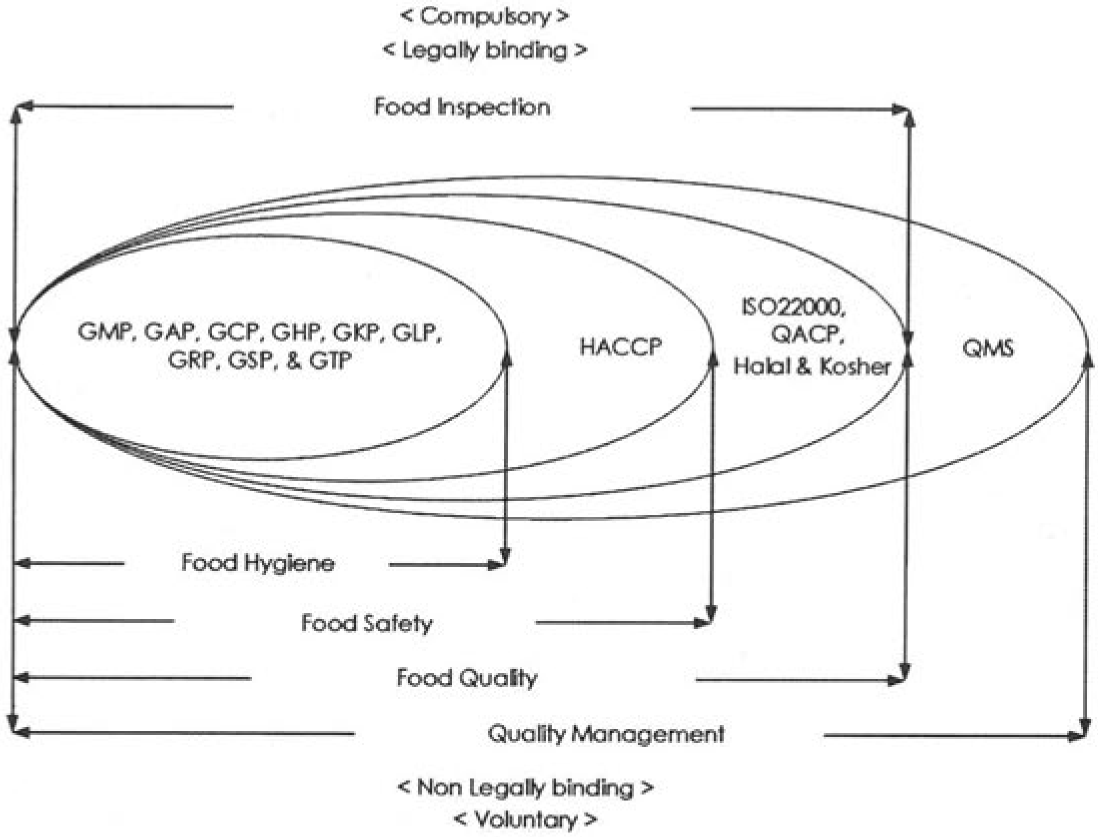

Figure 16. A diagrammatic representation of relationship between GMP, GAP, GHP, GCP, GKP, GLP, GRP, GSP and GTP, connecting with HACCP, QACP/Halal/Kosher and QMS, within the respective confines of food hygiene, safety, quality and QM (Source: Sikora & Strada [47] with modifications). GMP = Good Manufacturing Practice; GAP = Good Agricultural Practice; GHP = Good Hygiene Practice; GLP = Good Laboratory Practice; GRP = Good Retail Practice; GSP = Good Storage Practice; GTP = Good Transport Practice; HACCP = Hazard Analysis and Critical Control Points; QACP = Quality Assurance Control Points; QMS = Quality Management System; ISO = International Standard Organization

halal integrity[233] In the USA, food retailers especially the larger ones increasingly ensure that individual supplies enforce appropriate (good) practices to assure produce safety via GAPs, GMPs, and HACCP.[156] GCP guidelines could embrace a hybrid approach based on GMP guidelines combined with HACCP.[309] To advance the progress of the food quality system, both GMP and GHP would incorporate a prerequisite program (in traditional operations) that involves HACCP implementation.[97] HACCP is legally bound in the EU by Directive 93/43/EEC on the hygiene of foodstuffs. HACCP system is compulsorily applied in Poland by law on health conditions of food and nutrition – obligatory for medium/large food processing production plants. For small enterprises, GMP and GHP are applied.[101] Regardless of country, the implementation of HACCP fortifies the food safety in any given food establishment.

QM – a block of interrelated activities within the agro-food product industry that strongly connects food manufacturers with consumers.[240] Specifically, factors affecting product quality can include: a) customer requirements; b) product specifications, c) planning; d) purchasing and supplier assurance; e) purchased product/manufacturing process control; f) product control; g) inspection and testing; h) food safety management, and i) dispatch and distribution. When the above-mentioned (factors) are effectively organised to improve product quality, QM in the agro-food industry would increase control on product safety/quality given the changing consumer requirements, environmental concerns, increased competition as well as government interests.[240,310] QM standards when adopted bring about competitive advantages, which explain why some (agro-food) establishments prefer one standard type compared to another.[85] To implement any QM system, understanding the (quality) standard the product/service is certified with is key. To implement QM may come with its own (peculiar/specific) challenges such as a) cost reduction; b) on-time delivery; c) top management lack of commitment; d) lack of qualified personnel; e) lack of raw materials; f) lack of employee training; g) inadequate teamwork; h) insufficient quality process documentation; as well as i) challenges regarding QM information interpretation.[219,311–313]

Within the agro-food industry, QM system targets to improve food product quality, as underpinned by such attributes as food safety, value, package, process, and nutrition. Some agro-food product industries would have some flexibility to implement quality standards particularly (external – based) quality certifications given the differences in hierarchical management levels.[17] A diagrammatic representation of the relationship between GMP, GAP, GHP, GCP, GKP, GLP, GRP, GSP, and GTP, connecting with HACCP, QACP/Halal/Kosher and QMS, within the respective confines of food hygiene, safety, quality, and QM, is displayed in Fig. 16. Both compulsory (legally binding) and voluntary (non-legally binding) aspects/constructs of the QM framework within (any given) agro-food industry can be seen. From Fig. 16, we also see the legally binding aspects of food hygiene, safety, and quality are seen to clearly interconnect. Therefore, when an agro-food unit/enterprise has been successfully implemented, in the likes of GCP, GHP, GMP, GAP, GKP – all of which do fall under/within the HACCP domains, the next target should be QM, which would utilise the quality standard and system that the industry has deemed as the most appropriate/suitable.[47] Specifically, kosher and halal, are equally safety standards in their own right, can be seen placed alongside the QACP. To reiterate, 'assurance' relates to product quality, and involves QA together with GHP, GMP, HACCP up to QACP, whereas 'management' relates to the establishment's/unit's overall layout/organisation with respect to product quality, which connects through quality management system (QMS) to ISO 9000, ISO 22000, etc.[47] It is to improve the food product quality that the integration of quality standards happened. For example, the ISO 22000 integrated both ISO 9001:2000 and HACCP system, which made the food quality and safety standards more effective.[43]

To implement QM production processes, there has to be an increased level of product quality robustly focused to ensure consumer satisfaction, which is among key facets that underpins the effective working of agro-food industry/sector with such programs as GMP, GHP, QACP, GAP, GCP, GKP (Good Kitchen Practice) and HACCP.[47,257] For instance, GMP requires that the agro-food industry must meet food safety requirements, which even to the food handlers must undertake GMP training and refresher courses for continued and effective assimilation of work philosophy.[218] Although GHP and GMP have similar scope, both follow the principle of 'write down how you do it, do as you have written it down'. Whereas QA/QM procedures depend exclusively on the agro-food unit, all hygiene-sanitary requirements have to comply with the existing national regulatory body.[43] In the QM context, HACCP systematically targets the implementation of food safety via the QA principle, which makes each food company, enterprise/production line to adapt its QACP unique.[47]

With the relevant literature synthesised thus far, we can see that the QM appears strategically situated with high promise to elevate food hygiene quality standards and its associated processes. This would corroborate with the researches of earlier quality experts/workers[306,310,314] that emphasised that QM practices contribute to the overall industry performance to secure competitive advantage. Essentially, it is not establishing the QM system within the agro-food product industry that really matters, the real deal is about maintaining and sustaining it. Maintaining the QM system requires planning, organisation, and establishment of a workable and viable routine. Oftentimes, the maintenance work can be either overlooked or postponed, and this is not profitable. Last-minute QM activities should, therefore, be avoided so as not to lose sight of the required corrective actions. Useful examples of QM maintenance can include: (a) management review; (b) internal quality audit; (c) document control; and (d) quality record-keeping.[240] In addition, if QM were to be based on ISO 9000 standard, it could cover such aspects as: (a) management of the organisation; (b) management of resources; (c) process of product realisation; (d) measurements; (e) analysis; and (f) improvement.[43] Strengthening and essentially, sustaining the QM within the agro-food industry signals its usefulness, despite being a non-obligatory (that is, voluntary) system, which someday would eventually become the de facto requirement. From the above-mentioned, QM remains very promising to coordinate the implementation of food hygiene quality safety standards and its related processes.

Nonetheless, process control/standardisation, benchmarking/harmonisation, traceability, food inspection/legislations, risk assessment, validation/verification, and personnel assessment/training altogether cumulate the supplementary essentials that facilitate QM's progress within the agro-food products industry. Despite the sensitive nature of agro-food products and complexities of the supply chain, the QM has the potential to enhance consumer protection/safety notwithstanding the diverse elements that affect agro-food products, from pollution, industrial processes, variations in consumer preference, to the perishability of fresh foodstuffs. As such, QM's performance measurement system indicators appropriately reflect quality aspects of both products and processes.[269] Besides traceability systems to tackle the growing consumer food safety challenges/issues,[47] process standardisation of the agro-food product industry would connect with all the quality implementation levels, although each (implementation level) would have to be subject to some form of validation and verification.[37] Nonetheless, the effective production of safe/wholesome (agro)food products can be accomplished via hazard prevention and process improvement strategies. Through this, the HACCP verification emerges as a preventive-based mode of operation. If the HACCP plan is not valid, food product safety will not be completely assured. Oftentimes, validating the effectiveness of control measures employed in food production would require some level of microbiological competences as well as expertise.[288]

Concluding remarks

If QM is to work, moral values have to be developed and maintained, and this is essentially true to the agro-food product industry. Through food quality safety standards, food processors are obliged to ensure food products meet the required quality safety standards. Good practices, from GHP, GAP, GMP, GCP to GTP, all have a common objective if carried out effectively and efficiently, which is, to compulsorily ensure the high quality level of food product hygiene and consumer safety. Through the combined efforts of HACCP and QA control points (QACP) that targets to ensure improved food hygiene, both quality and safety levels can be further enhanced and sustained. This makes the agro-food product industry capable of achieving as well as reaching some desirable QM targets. When good practices are achieved with HACCP, the next target will be that of QM, which would have to utilise the quality standard/system that has been deemed as the most appropriate by the food enterprise/unit. Considering the complexities of the agro-food product supply chain, QM appears strategically situated to advance food hygiene quality standards and related processes. However, establishing the QM system within the agro-food product establishment/unit is not the real deal, it is about maintaining and sustaining it, which certainly requires consistency in planning, organisation, and establishment of a routine. As ISO promotes standardisation of processes, food industries can greatly benefit from ISO22000. In addition, Kosher and Halal are food quality safety standards in their respect as both are placed alongside QACP. Notably, process control/standardisation, benchmarking/harmonisation, traceability, food inspection/legislations, risk assessment, validation/verification, and personnel assessment/training are supplementary essentials useful in facilitating the functioning of QM in the agro-food product industry.

In addition, how (all) good practices discussed in this current work operate under Kosher and Halal quality standards are among research areas that requires additional investigations to supplement existing literature. Interestingly, with respect to Halal, a number of emerging researches have involved good practices, [315–317] which suggests that more studies should be encouraged, in order to build up the body of knowledge. Considering COVID-19 global pandemic that has spread across the continents,[318] and despite that there is no evidence of yet regards transmission through food, the real importance of food safety particularly good practices across all stages of the food supply chain cannot be overemphasised.[319] Because of the COVID-19 pandemic situation, and here in Poland as at the time of this current review, which is similar to many other countries' situation around the globe, the food establishments/firms have had no option but to step-up their good (food hygiene quality safety) practices.

Future prospects

Consumers and food unit managers as well as owners across the globe would definitely perceive QM in different ways. Therefore, it would be useful to know how QM functions in food establishments through the standpoint of both consumers and food unit managers/owners, aiming to improve food quality standards and this could be the direction for a future research. In addition, how cleaner food production could be achieved through the action as well as implementation of (food) hygiene quality safety practices/standards and subsequently enhanced, starting from the retail to supermarket/food industrial levels could be another direction of future research. Given the challenges that confront QMS in the food industry, further research is required that would aim to further understand the problems/non-conformities that emanate during the auditing of (QMS) systems. Understanding the factors that bring about such problems/non-conformities during the auditing process of QMS (and FSMS) would be useful to delineate.

The cost of adopting and subsequently implementing ISO standards is understood to scare away the small-scale food industries around the globe. It would be useful for future studies to seek for a low-cost approach that would help ascertain the quality of agro-food products, based on the compulsory QM aspects, which would involve good practices, food hygiene, quality and safety. This could be in the form of a questions-based framework, which would at the same time, target the quality aspects of the food technological processes especially those of small-scale food industries, who are unable to afford to implement these QM-based ISO standards. Such questions-based framework could help lay a foundation of understanding which QM approach would be more applicable. It could also help make more key aspects of QM to become a reality specific to the small-scale food industries. Besides, there is need for additional literature synthesis/studies to help establish how food safety knowledge contributes to serving as a robust quality tool for FSMS, especially from the QM standpoint. Besides the implementation of ISO standards, it would be useful for future studies to compare ISO certifications and their locations/sites across the continents and food sectors, as it might provide a clue regards the extent QM has progressed across various countries.

Another area not covered in this review that needs attention is deducing the novelties that might be existing in the latest ISO9001:2015, applicable to the food industry/sector. In this direction, future reviews should look at the context of management principles, and risk-based approaches. Another area that has not been captured in this current review is total quality management (TQM) as it pertains to the agro-food industry. Thus, a robust literature synthesis is warranted, particularly to examine how TQM tools are applicable and relevant for (food) product development, and how such could bring about improvement from small-medium to large-scale production. There is also need for robust analysis of ISO 9001 and 22000 certificates and sites within the global agro-food sector to ascertain the current status, trend across countries, and degree of association with respect to certificates/sites versus countries. This could be performed in the form of data mining/visualisation, and with respect to expanding the body of knowledge, the use of systematic review, and or meta-analysis becomes very useful.. All emergent data from the above-mentioned future researches would surely help to supplement existing information.

Acknowledgments

Thanks to Dott. Giacomo Sardo (IRBIM CNR, Mazara del Vallo, Italy) for his help with Figs. 11 and Figs.16.

Funding

Funding by Wrocław University of Environmental and Life Sciences (Wrocław, Poland) to COR Okpala and M Korzeniowska is gratefully acknowledged.

ORCID

Charles Odilichukwu R. Okpala http://orcid.org/0000-0003-4475-8887
Małgorzata Korzeniowska http://orcid.org/0000-0002-0300-0407

Author contributions

COR Okpala conceptualised the idea, collected the data, compiled and wrote the manuscript. M Korzeniowska contributed to, and corrected the manuscript. All the involved authors contributed to the scientific content and approved the final submitted manuscript.

Conflicts of interest

The authors declare no conflict of interest related to the contents of this manuscript.

References

[1] Sousa, R.; Voss, C. A. Quality Management Revisited: A Reflective Review and Agenda for Future Research. *J. Oper. Manag.* 2002, *20*(1), 91–109.10.1016/S0272-6963(01)00088-2.

[2] Dean, J.; Bowen, D. Managing Theory and Total Quality: Improving Research and Practice through Theory Development. *Acad. Manag. Rev.* 1994, *19*(3), 392–418.10.5465/amr.1994.9412271803.

[3] Caswell, J. A.; Bredahl, M. E.; Hooker, N. H. How Quality Management Metasystems are Affecting the Food Industry. *Applied Econ. Perspect. Policy.* 1998, *20*(2), 547–557. DOI: 10.2307/1350007.

[4] Singh, A. K.; Khanduja, D. Defining Quality Management in Auto Sector: A Six-Sigma Perception Procedia Mat. *Sci.* 2014, *5*, 2645–2653. DOI: 10.1016/j.mspro.2014.07.526.

[5] Evans, J. R.; Dean, J. W. *Total Quality: Management, Organization and Strategy*, 2nd Edition; South-Western College Publishing: Cincinnati - OH, 2000. pp. 376. ISBN 0324012764.

[6] Mehra, S.; Hoffman, J. M.; Sirias, D. TQM as Management Strategy for the Next Millennia. *Int. J. Oper. Prod. Manag.* 2001, *21*(5/6), 855–876. DOI: 10.1108/01443570110390534.

[7] Robinson, C. J.; Malhotra, M. K. Defining the Concept of Supply Chain Quality Management and Its Relevance to Academic and Industrial Practice. *Int. J. Production Econ.* 2005, *96*(3), 315–337. DOI: 10.1016/j.ijpe.2004.06.055.

[8] Dow, D.; Samson, D.; Ford, S. Exploding the Myth: Do All Quality Management Practices Contribute to Superior Quality Performance. *Prod. Oper. Manag.* 1999, *8*(1), 1–27. DOI: 10.1111/j.1937-5956.1999.tb00058.x.

[9] Moulin, M.;. Performance Measurement Definitions: Linking Performance Measurement and Organizational Excellence. *Int. J. Health Care Qual. Assur.* 2007, *2*(3), 181–183. DOI: 10.1108/09526860710743327.

[10] Ahire, S. L.; Golhar, D.; Waller, M. Development and Validation of TQM Implementation Constructs. *Decision Sci.* 1996, *27*(1), 23–56. DOI: 10.1111/j.1540-5915.1996.tb00842.x.

[11] Anderson, J.; Rungtusanatham, M.; Schroeder, R.; Devaraj, S. A Path Analytic Model of A Theory of Quality Management Underlying the Deming Management Method: Preliminary Empirical Findings. *Decision Sci.* 1995, *26*(5), 637–658. DOI: 10.1111/j.1540-5915.1995.tb01444.x.

[12] Powell, T.;. TQM as Competitive Advantage: A Review and Empirical Study. *Strat. Manag. J.* 1995, *16*(1), 15–37. DOI: 10.1002/smj.4250160105.

[13] Saraph, J.; Benson, P.; Schroeder, R. G. An Instrument for Measuring the Critical Factors of Quality Management. *Decision Sci.* 1989, *20*(4), 810–829. DOI: 10.1111/j.1540-5915.1989.tb01421.x.

[14] Flynn, B.; Schroeder, R.; Sakakibara, S. The Impact of Quality Management Practices on Performance and Competitive Advantage. *Decision Sci.* 1995, *26*(5), 659–692. DOI: 10.1111/j.1540-5915.1995.tb01445x.

[15] Okpala, C. O. R., &.; Korzeniowska, M. Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. *Front. Nutrit.* 2020, *7*, 578941. DOI: 10.3389/fnut.2020.578941.

[16] Botta, R.;. *Evaluation of Seafood Freshness Quality* ISBN 047118509; VCH Publishers Inc.: New York: USA, 1995; pp 180.

[17] Krieger, S.; Schiefer, G. (2006). Quality Systems in the Agri-food Industry – Implementation, Cost, Benefit and Strategies. Poster presentation at the International Association of Agricultural Economists Conference, Gold Coast, Queensland, Australia, August 12-18, 2006; doi: 10.22004/ag.econ.25795.
[18] Juran, J. M.;. The Upcoming Century of Quality. *Qual. Progr.* 1994, *27*(8), 29–37.
[19] Okpala, C. O. R.;. Towards Sustaining Global Food Systems for the Future. *Front. Sust. Food Syst.* 2020, *4*, 3. DOI: 10.3389/fsufs.2020.00003.
[20] Dora, M.; Kumar, M.; Goubergen, D. V.; Molnar, A.; Gellynck, X. Food Quality Management System: Reviewing Assessment Strategies and Feasibility Study for European Food Small and Medium-sized Enterprises. *Food Control.* 2013, *31*(2), 607–616. DOI: 10.1016/j.foodcont.2012.12.006.
[21] Costa-Font, M.; Revoredo-Giha, C. (2020). Covid-19: The Underlying Issues Affecting the UK's Food Supply Chains. LSE Business Review https://blogs.lse.ac.uk/businessreview/2020/03/25/covid-19-the-underlying-issues-affecting-the-uks-food-supply-chains/ Accessed 17 May 2020, 15.30 h GMT.
[22] Voysey, P. A.; Brown, M. Microbiological Risk Assessment: A New Approach to Food Safety Control. *Int. J. Food Microbiol.* 2000, *58*(3), 173–179. DOI: 10.1016/S0168-1605(00)00271-3.
[23] Aruoma, C. I.;. The Impact of Food Regulation on the Food Supply Chain. *Toxicology.* 2006, *221*(1), 119–127. DOI: 10.1016/j.tox.2005.12.024.
[24] Bendekovic, J.; Nalentina, D.; Nola, I. (2015). Food Safety and Food Quality in the Supply Chain, pp. 1–13 (http://bib.irb.hr/datoteka/786708.TP_Bendekovic_Nalentina_Nola.pdf) Accessed 17 March 2020, 15.01 h GMT
[25] Hillers, V. N.;. Food Safety and Quality Topics in National Plans of Action for Nutrition. *Food Control.* 1997, *8*(1), 5–11. DOI: 10.1016/S0956-7135(96)00055-2.
[26] Kotsanopoulos, K. V.; Arvanitoyannis, I. S. The Role of Auditing, Food Safety, and Food Quality Standards in the Food Industry: A Review. *Compr. Rev. Food Sci. Food Saf.* 2017, *16*(5), 760–775. DOI: 10.1111/1541-4337.12293.
[27] Anyanwu, R. C.; Jukes, D. J. Food Safety Control Systems for Developing Countries. *Food Control.* 1990, *1*(1), 17–26. DOI: 10.1016/0956-7135(90)90116-T.
[28] Selmat, J.; Iqbal, S. Z.,Eds. 2016. *Food Safety: Basic Concepts, Recent Issues and Future Challenges.* Springer International Publishing:Switzerand. 164. ISBN: 978-3-319-39253-0
[29] Okpala, C. O. R.; Ezeonu, I. M. Food Hygiene/microbiological Safety in the Typical Household Kitchen: Some Basic 'Must Knows' for the General Public. *J. Pure Appl. Microbiol.* 2019, *13*(2), 697–713. DOI: 10.22207/JPAM.13.2.06.
[30] Riaz, M. N.; Chaudry, M. M. The Value of Halal Food Production. *Int. News Fats Oils Related Mat.* 2004, *15*(11), 698–701.
[31] Savov, A. V.; Kouzmanov, G. B. Food Quality and Safety Standards at a Glance. *Biotechnol. Biotechnolog. Equip.* 2009, *23*(4), 1462–1468. DOI: 10.2478/V10133-009-0012-8.
[32] Moberg, L.;. Good Manufacturing Practices for Refrigerated Foods. *J. Food Prot.* 1989, *52*(5), 363–367. DOI: 10.4315/0362-028X-52.5.363.
[33] Bilska, A.; Kowalski, R. Food Quality and Safety Management. *LogForum Sci. J. Logist.* 2014, *10*(3), 351–361. e 1734-459X.
[34] Wongsprawmas, R.; Canavari, M.; Waisarayutt, C. Food Safety Assurance System for Fresh Produce Production in Thailand: A Review. *Qual. Assur. Saf. Crops Food.* 2015a, *7*(1), 73–88. DOI: 10.3920/QAS2013.0255.
[35] Śmiechowska, M.; Kłobukowski, F. Quality Assurance of Food versus Limiting Food Loss and Waste. *J. Manag. Finance.* 2015, *13*(2), 93–103.
[36] Kibe, E. N.; Wanjau, K. The Effect of Quality Management Systems on the Performance of Food Firms in Kenya. *IOSR J. Business Manag.* 2014, *16*(5), 61–72. DOI: 10.9790/487X-16526172.
[37] Jacxsens, L.; Luning, P. A.; Marcelis, W. J.; Van Boekel, T.; Roviram, J.; Oses, S.; Kousta, M.; Drosinos, E.; Jasson, V.; Uyttendaele, M.;, et al. Tools for the Performance Assessment and Improvement of Food Safety Management Systems. *Trends Food Sci. Technol.* 2011, *22*, S80–89. DOI: 10.1016/j.tifs.2011.02.008.
[38] Karipidis, P.; Athanassiadis, K.; Aggelopoulos, S.; Giompliakis, E. Factors Affecting the Adoption of Quality Assurance Systems in Small Food Enterprises. *Food Control.* 2009, *20*(2), 93–98. DOI: 10.1016/j.foodcont.2008.02.008.
[39] Luning, P. A.; Marcelis, W. J.; Rovira, J.; Van Der Spiegel, M.; Uyttendaele, M.; Jacxsens, L. Systematic Assessment of Core Assurance Activities in a Company Specific Food Safety Management System. *Trends Food Sci. Technol.* 2009, *20*(6–7), 300–312. DOI: 10.1016/j.tifs.2009.03.003.
[40] Trienekens, J.; Zuurbier, P. Quality and Safety Standards in the Food Industry, Developments and Challenges. *Int. J. Prod. Econ.* 2008, *113*(1), 107–122. DOI: 10.1016/j.ijpe.2007.02.050.
[41] Raspor, P.; Jevšnik, M. Good Nutritional Practice from Producer to Consumer. *Crit. Rev. Food Sci. Nutr.* 2008, *48*(3), 276–292. DOI: 10.1080/10408390701326219.
[42] Raspor, P.;. Total Food Chain Safety: How Good Practices Can Contribute? *Trends Food Sci. Technol.* 2008, *19*(8), 405–412. DOI: 10.1016/j.tifs.2007.08.009.
[43] Knaflewska, J.; Pospiech, E. Quality Assurance Systems in Food Industry and Health Security of Food. *Acta Scientiarum Polonorum Technologia Alimentaria.* 2007, *6*(2), 75–85. 1644-0730.

[44] Da Cruz, A. G.; Cenci, S. A.; Maia, M. C. A. Quality Assurance Requirements in Produce Processing. *Trends Food Sci. Technol.* 2006a, *17*(8), 406–411. DOI: 10.1016/j.tifs.2006.03.003.

[45] Manning, L.; Baines, R. N.; Chadd, S. A. Quality Assurance Models in the Food Supply Chain. *Br. Food J.* 2006, *108*(2), 91–104. DOI: 10.1108/00070700610644915.

[46] Doyon, G.; Lagimonière, M. Traceability and Quality Assurance Systems in Food Supply Chains. *Stewart Postharvest Rev.* 2006, *2*(3), 1–16.

[47] Sikora, T.; Strada, A. Safety and Quality Assurance and Management Systems in Food Industry: An Overview. In *The Food Industry in Europe*. Agricultural University of Athens: Ateny, Greece, 2005, pp. 85–95.http://www.ip.aua.gr/Studies/Sikora-Strada_final.pdf

[48] Manning, L.; Baines, R. N. Effective Management of Food Safety and Quality. *Br. Food J.* 2004, *106*(8), 598–606. DOI: 10.1108/00070700410553594.

[49] Jatib, I.;. Food Safety and Quality Assurance Key Drivers of Competitiveness. *Int. Food Agribusiness Manag. Rev.* 2003, *6*(1), 1–19.

[50] Costa, A. I. A.; Dekker, M.; Jongen, W. M. F. Quality Function Deployment in the Food Industry: A Review. *Trends Food Sci. Technol.* 2000, *11*(9–10), 306–314. DOI: 10.1016/S0924-2244(01)00002-4.

[51] Barendsz, A. W.;. Food Safety and Total Quality Management. *Food Control.* 1998, *9*(2–3), 163–170. DOI: 10.1016/S0956-7135(97)00074.

[52] Okpala, C. O. R.; Sardo, G.; Vitale, S.; Bono, G.; Arukwe, A. Hazardous Properties and Toxicological Update of Mercury: From Fish Food to Human Health Safety Perspective. *Crit. Rev. Food Sci. Nutr.* 2018, *58*(12), 1986–2001. DOI: 10.1080/10408398.2017.1291491.

[53] Bolton, A.;. 1997. *Quality Management System for the Food Industry: A Guide to ISO9001/2.* Blackie Academic Professional/Chapman & Hall:London UK. 193. ISBN 0751403032

[54] Velasquez, M.; Andre, C.; Shanks, T. S. J.; Meyer, M. J. (2010). *What Is Ethics*? Markkula Center for Applied Ethics at Santa Clara University, Published in Website, January 1, 2010. (www.scu.edu/ethics/ethics-resources /ethical-decision-making/what-is-ethics/ Accessed 20 January 2019, 05.53 GMT).

[55] Wicks, A. C.;. The Value Dynamics of Total Quality Management: Ethics and the Foundations of TQM. *Business Ethics Quart.* 2001, *11*(3), 501–535. DOI: 10.2307/3857851.

[56] Ahmed, P. K.; Machold, S. The Quality and Ethics Connection: Toward Virtuous Organisations. *Total Qual. Manag. Business Excellence.* 2004, *15*(4), 527–545. DOI: 10.1080/1478336042000183604.

[57] Fisscher, O.; Nijhof, A. Implications of Business Ethics for Quality Management. *TQM Mag.* 2005, *17*(2), 150–160. DOI: 10.1108/09544780510583227.

[58] Barney, J. B.; Hansen, M. H. Trustworthiness as a Source of Competitive Advantage. *Strat. Manag. J.* 1994, *15*(S1), 175–190. DOI: 10.1002/smj.4250150912.

[59] Hosmer, L. T.;. Trust: The Connecting Link between Organization Theory and Philosophical Ethics. *Acad. Manag. Rev.* 1995, *20*(2), 379–403.10.5465/amr.1995.9507312923.

[60] De Leede, J.;. *Bottom-up Innovation; on the Contribution of Semi-Autonomous Groups in Product and Process Innovation*; Kluwer Bedrijfsinformatie: Deventer, 1997.

[61] Medeiros, L. C.; Hillers, V. N.; Chen, G.; Bergmann, V.; Kendall, P.; Schroeder, M. Design and Development of Food Safety Knowledge and Attitude Scales for Consumer Food Safety Education. *J. Am. Diet. Assoc.* 2004, *104* (11), 1671–1677. DOI: 10.1016/j.jada.2004.08.030.

[62] Medeiros, L. C.; Hillers, V. N.; Kendall, P.; Mason, A. Evaluation of Food Safety Education for consumers. *Journal of Nutrition Education.* 2001, *33*, S27–S34. DOI: 10.1016/s1499-4046(06)60067-5.

[63] Unusan, N.;. Consumer Food Safety Knowledge and Practices in the Home in Turkey. *Food Control.* 2007, *18*(1), 45–51.

[64] Albert, J. A.;. Food Safety Knowledge and Practices of Consumers Inthe USA. *J. Consumer Stud. Home Econ.* 1995, *19*(2), 119–134. DOI: 10.1111/j.1470-6431.1995.tb00537.x.

[65] Bruhn, C. M.; Schutz, H. G. Consumer Food Safety Knowledgeand Practices. *J. Food Saf.* 1999, *19*(1), 73–87. DOI: 10.1111/j.1745-4565.1999.tb00235.x.

[66] Rimal, A.; Fletcher, S. M.; McWatters, K. H.; Misra, S. K.; Deodhar, S. Perception of Food Safety and Changes in Food Consumptionhabits: A Consumer Analysis. *Int. J. Consumer Stud.* 2001, *25*(1), 43–52. DOI: 10.1111/j.1470-6431.2001.00162.x.

[67] Collis, B.; Winnips, K. Two Scenarios for Productive Learningenvironments in the workplace.British. *British Journal of Educational Technology.* 2002, *33*(2), 133–148. DOI: 10.1111/1467-8535.00248.

[68] Jevšnik, M.; Hlebec, V.; Raspor, P. Food Safety Knowledge and Practices among Food Handlers in Slovenia. *Food Control.* 2008, *19*(2), 1107–1118. DOI: 10.1016/j.foodcont.2007.11.010.

[69] Sharif, L.; Obaidat, M. M.; Al-Dalalah, M. Food Hygiene Knowledge, Attitudes, and Practices of the Food Handlers in the Military Hospitals. *Food Nutr. Sci.* 2013, *4*(3), 245–251. DOI: 10.4236/fns.2013.43033.

[70] Webb, M.; Morancie, A. Food Safety Knowledge of Foodservice Workers at a University Campusby Education Level, Experience, and Food Safety Training. *Food Control.* 2015, *50*, 259–264. DOI: 10.1016/j.foodcont.2014.09.002.

[71] Johnson, A. E.; Donkin, A. J. M.; Morgan, K.; Lilley, J. N.; Neale, R. J.; Page, R. M.; Silburn, R. Food Safety Knowledge and Practice among Elderly People Living at Home. *J Epidemiol Community Health*. 1988, *52*(11), 745–748. DOI: 10.1136/jech.52.11.745.

[72] Kennedy, J.; Jackson, V.; Blair, I. S.; McDowell, D. A.; Cowan, C.; Bolton, D. J. Food Safety Knowledge of Consumers and the Microbiological and Temperature Status of Their Refrigerators. *J. Food Prot.* 2005, *68*(7), 1421–1430. DOI: 10.4315/0362-028X-68.7.1421.

[73] Mihalache, O. A.; Dumitrașcu, L.; Nicolau, A. I.; Borda, D. Food Safety Knowledge, Food Shopping Attitude and Safety Kitchen Practices among Romanian Consumers: A Structural Modelling Approach. *Food Control*. 2021, *120*, 107545. DOI: 10.1016/j.foodcont.2020.107545.

[74] Omemu, A. M.; Aderoju, S. T. Food Safety Knowledge and Practices of Street Food Vendors in the City of Abeokuta. *Food Control*. 2008, *19*(4), 396–402. DOI: 10.1016/j.foodcont.2007.04.021.

[75] Taha, S.; Osaili, T. M.; Saddal, N. K.; Al-Nabulsi, A. A.; Ayyash, M. M.; Obaid, R. S. Food Safety Knowledge among Food Handlers in Food Service Establishments in United Arab Emirates. *Food Control Vol.* April, 2020, *110*, 106968. DOI: 10.1016/j.foodcont.2019.106968.

[76] Bolton, D. J.; Meally, A.; Blair, I. S.; McDowell, D. A.; Cowan, C. Food Safety Knowledge of Head Chefs and Catering Managers in Ireland. *Food Control*. 2008, *19*(3), 291–300. DOI: 10.1016/j.foodcont.2007.04.006.

[77] Hertzman, J.; Barrash, D. An Assessment of Food Safety Knowledge and Practices of Catering Employees. *Br. Food J.* 2007, *109*(7), 562–576. DOI: 10.1108/00070700710761545.

[78] Osaili, T. M.; Obeidat, B. A.; Abu Jamous, D. O.; Bawadi, H. A. Food Safety Knowledge and Practices among College Female Students in North of Jordan. *Food Control*. 2011, *22*(2), 269–276. DOI: 10.1016/j.foodcont.2010.07.009.

[79] Sanlier, N.; Konaklioglu, E. Food Safety Knowledge, Attitude and Food Handling Practices of Students. *Br. Food J.* 2012, *114*(4), 469–480. DOI: 10.1108/00070701211219504.

[80] Marklinder, I.; Ahlgren, R.; Blücherc, A.; Börjesson, S. M. E.; Hellkvist, F.; Moazzami, M.; Schelin, J.; Zetterström, E.; Eskhult, G.; Danielsson-Tham, M. L. Food Safety Knowledge, Sources Thereof and Self-reported Behaviour among University Students in Sweden. *Food Control*. 2020, *113*, 107130. DOI: 10.1016/j.foodcont.2020.107130.

[81] Zhou, J.; Jin, S. *Food Safety Management in China: A Perspective from Food Quality Control System* ISBN: 978-981-4447-75-1; World Scientific Publishing Co. Pte. Ltd.: Zhejiang University Press, China, 2013; pp 240.

[82] Alli, I.;. *Food Quality Assurance: Principles and Practices* ISBN 1566769302; CRC Press: New York-USA, 2004; pp 141.

[83] Nguz, K.;. Assessing Food Safety System in sub-Saharan Countries: An Overview of Key Issues. *Food Control*. 2007, *18*(2), 131–134. DOI: 10.1016/j.foodcont.2005.09.003.

[84] Hobbs, J. E.;. Incentive Structures for Food Safety and Quality Assurance: An International Comparison. *Food Control*. 2002, *13*(2), 77–81. DOI: 10.1016/S0956-7135(01)00103-7.

[85] Hammoudi, A.; Hoffmann, R.; Surry, Y. Food Safety Standards and Agri-food Supply Chains: An Introductory Overview. *Eur. Rev. Agri. Econ.* 2009, *36*(4), 469–478. DOI: 10.1093/erae/jbp044.

[86] Vellema, S.; Boselie, D. *Cooperation and Competence in Global Food Chains: Perspectives on Food Quality and Safety* ISBN 9789042302327; Shaker Publishing: Maastricht, 2003; pp 208.

[87] Handschuch, C.; Wollni, M.; Villalobos, P. Adoption of Food Safety and Quality Standards among Chilean Raspberry Producers – Do Smallholders Benefit? *Food Policy*. 2013, *40*, 64–73. DOI: 10.1016/j.foodpol.2013.02.002.

[88] Jaffee, S.;. *From Challenge to Opportunity: The Transformation of the Kenyan Fresh Vegetable Trade in the Context of Emerging Food Safety and Other Standards*; World Bank: Washington USA, 2004.

[89] Wilcock, A. E.; Ball, B.; Fajumo, A. Effective Implementation of Food Safety Initiatives: Managers', Food Safety Coordinators' and Production Workers' Perspectives. *Food Control*. 2011, *22*(1), 27–33. DOI: 10.1016/j.foodcont2010.06.005.

[90] Herzfield, T.; Drescher, L. S.; Grebitus, C. Cross-national Adoption of Private Food Quality Standards. *Food Policy*. 2011, *36*(3), 401–411. DOI: 10.1016/j.foodpol.2011.03.006.

[91] Theuvsen, L.; Spiller, A.; Peupert, M.; Jahn, G.,Eds. 2007. *Quality Management in Food Chains*. Wageningen Academic Publishers:The Netherlands. 509. 10.3920/978-90-8686-605-2

[92] Al-Mazeedi, H. M.; Regenstein, J. M.; Riaz, M. N. The Issue of Undeclared Ingredients in Halal and Kosher Food Production: A Focus on Processing Aids. *Compr. Rev. Food Sci. Food Saf.* 2013, *12*(2), 228–233. DOI: 10.1111/1541-4337.12002.

[93] Varzakas, T.; Tzia, C. 2016. *Handbook of Food Processing, Food Safety, Quality and Manufacturing Processes*. Florida, USA. CRC Press:676. ISBN: 978-1-4987-2178-3

[94] Bernhardt, H. W.; Raschke, A. Good Manufacturing Practice (GMP) in Cane Sugar Fractoris. *Proc. South Afr. Sugar Technol. Assoc.* 1998, *72*, 215–218.

[95] Rodmanee, S.; Huang, W. C. Hygiene and Manufacturing Practices, Interagency Collaboration, and A Proposal for Improvement: A Case Study of Community Food Enterprise in Thailand. *Int. J. Soc. Sci. Hum.* 2013, 3(3), 222–226. DOI: 10.7763/IJSSH.2013.V3.232.

[96] Arkeman, Y.; Herlinawati, T.; Wibawa, D. S.; Adinegoro, H. Formulating Strategies to Improve Food Safety of Bakery Small-medium Enterprises through Good Manufacturing Practice. *J. Teknologi Industri Pertanian*. 2015, *25*(1), 43–51. 0216-3160.

[97] Amoa-Awua, W. K.; Ngunjiri, P.; Anlobe, J.; Kpodo, K.; Halm, M.; Hayford, A. E.; Jakobsen, M. The Effect of Applying GMP and HACCP to Traditional Food Processing at a Semi-commercial Kenkey Production Plan in Ghana. *Food Control*. 2007, *18*(11), 1449–1457. DOI: 10.1016/j.foodcont.2006.10.009.

[98] Santana, N. G.; Almeida, R. C. C.; Ferreira, J. S.; Almeida, P. F. Microbiological Quality and Safety of Meals Served to Children and Adoption of Good Manufacturing Practices in Public School Catering in Brazil. *Food Control*. 2009, *20*(3), 255–261. DOI: 10.1016/j.foodcont.2008.05.004.

[99] Cusato, S.; Gameiro, A. H.; Coarassin, C. H.; Sant'Ana, A. S.; Cruz, A. G.; Faria, J.; De, A. F. Food Safety Systems in a Small Dairy Factory: Implementation, Major Challenges, and Assessment of Systems' Performance. *Foodborne Pathogens Dis*. 2013, *10*(1), 6–12. DOI: 10.1089/fpd.2012.1286.

[100] Demirbaş, N.; Karagözlü, C. Constraints in Meeting Food Safety and Quality Requirements in the Turkish Dairy Industry: A Case Study of Izmir Province. *J. Food Prot*. 2008, *71*(2), 440–444. DOI: 10.4315/0362-028X-71.2.440.

[101] Konecka-Matyjek, E.; Turlejska, H.; Pelzner, U.; Szponar, L. Actual Situation in the Area of Implementing Quality Assurance Systems GMP, GHP and HACCP in Polish Food Production and Processing Plants. *Food Control*. 2005, *16*(1), 1–9. DOI: 10.1016/j.foodcont.2003.10.007.

[102] Martinez-Tomé, M.; Vera, A. M.; Antonia Murca, M. Improving the Control of Food Production in Catering Establishments with Particular Reference to the Safety of Salads. *Food Control*. 2000, *11*(6), 437–445. DOI: 10.1016/S0956-7135(00)00006-2.

[103] De Lima, D. P.; Medeiros, C. O.; Dardin, F. D.; Stangarlin-Fiori, L. Implementation of Good Hygiene Practices in Food Trucks with and without the Intervention of a Food Safety Expert. *J. Food Saf*. 2019, *39*(3), e12637. DOI: 10.1111/jfs.12637.

[104] Baluka, S. A.; Miller, R. A.; Kaneene, J. B. Hygienic Practices and Food Contamination in Managed Food Service Facilities in Uganda. *Afr. J. Food Sci*. 2015, *9*(1), 31–42. DOI: 10.5897/AJFS2014.1170.

[105] Jianu, C.; Goleţ, I. Knowledge of Food Safety and Hygiene and Personal Hygiene Practices among Meat Handlers Operating in Western Romania. *Food Control*. 2014, *42*, 214–219. DOI: 10.1016/j.foodcont.2014.02.032.

[106] Rahman, M. M.; Arif, M. T.; Bakar, K.; Tambi, Z. Food Safety Knowledge, Attitude and Hygiene Practices among the Street Food Vendors in Northern Kuching City, Sarawak. *BorneoScience*. 2016, *31*, 107–116.

[107] Wambui, J.; Karuri, E.; Lamuka, P.; Matofari, J. Good Hygiene Practices among Meat Handlers in Small and Medium Enterprise Slaughterhouses in Kenya. *Food Control*. 2017, *81*, 34–39. DOI: 10.1016/j.foodcont.2017.05.036.

[108] Saad, M.; See, T. P.; Adil, M. A. M. Hygiene Practices of Food Handlers at Malaysian Government Institutions Training Centers. *Procedia Soc. Behav. Sci*. 2013, *85*, 118–127. DOI: 10.1016/j.sbspro.2013.08.344.

[109] Upadhayaya, M.; Ghimire, B. Survey on Good Hygiene Practices in Retail Meat Shops in Butwal Municipality, Nepal. *Nepalese Veter. J*. 2018, *35*, 110–121. DOI: 10.3126/nvj.v35i0.25248.

[110] Ifeadike, C. O.; Ironkwe, O. C.; Adogu, P. O. U.; Nnebue, C. C. Assessment of the Food Hygiene Practices of Food Handlers in the Federal Capital Territory of Nigeria. *Trop. J. Med. Res*. 2014, *17*(1), 10–15. DOI: 10.4103/1119-0388.130175.

[111] Djekic, I.; Smigic, N.; Kalogianni, E. P.; Rocha, A.; Zamioudi, L.; Pacheso, R. Food Hygiene Practices in Different Establishments. *Food Control*. 2014, *39*, 34–40. DOI: 10.1016/j.foodcont.2013.10.035.

[112] Okpala, C. O. R.; Nwobi, O. C.; Korzeniowska, M. Assessing Nigerian Butchers' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods*. 2021a, *10*(6), 1165. DOI: 10.3390/foods10061165.

[113] Cortese, R. D. M.; Veiros, M. B.; Feldman, C.; Cavalli, S. B. Food Safety and Hygiene Practices of Vendors during the Chain of Street Food Production in Florianopolis, Brazil: A Cross-sectional Study. *Food Control*. 2016, *62*, 178–186. DOI: 10.1016/j.foodcont.2015.10.027.

[114] Ababio, P. F.; Adi, D. D. Evaluating Food Hygiene Awareness and Practices of Food Handlers in the Kumasi Metropolis. *Internet J. Food Safety*. 2012, *14*, 35–45.

[115] Kunadu, A. R. H.; Ofosu, D. B.; Aboagye, E.; Tano-Debrah, K. Food Safety Knowledge, Attitudes and Self-reported Practices of Food Handlers in Institutional Foodservice in Accra, Ghana. *Food Control*. 2016, *69*, 324–330. DOI: 10.1016/j.foodcont.2016.05.011.

[116] Sinkel, D.; Khouryieh, H.; Daday, J. K.; Stone, M.; Shen, C. Knowledge and Implementation of Good Agricultural Practices among Kentucky Fresh Produce Farmers. *Food Prot. Trends*. 2018, *38*(2), 111–121.

[117] Da Cruz, A. G.; Cenci, S. A.; Maia, M. C. A. Good Agricultural Practices in a Brazilian Produce Plant. *Food Control*. 2006b, *17*(10), 781–788. DOI: 10.1016/j.foodcont.2005.05.002.

[118] Nurul Islam, G. M.; Arshad, F. M.; Radam, A.; Alias, E. F. Good Agricultural Practices (GAP) of Tomatoes in Malaysia: Evidences from Cameron Highlands. *Afr. J. Bus. Manag*. 2012, *6*(27), 7969–7976.

[119] Wongsprawmas, R.; Canavari, M.; Waisarayutt, C. A Multi-stakeholder Perspective on the Adoption of Good Agricultural Practices in the Thai Fresh Produce Industry. *Br. Food J.* 2015b, *117*(9), 2234–2249. DOI: 10.1108/BFJ-08-2014-0300.

[120] Kokkinakis, E. N.; Boskou, G.; Fragkiadakis, G. A.; Kokkinaki, A. N.; Lapidakis, N. Microbiological Quality of Tomatoes and Peppers Produced under the Good Agricultural Practices Protocol AGRO 2-1 & 2-2 in Crete, Greece. *Food Control.* 2007, *18*(12), 1538–1546. DOI: 10.1016/j.foodcont.2006.12.002.

[121] Marine, S. C.; Martin, D. A.; Adalja, A.; Mathew, S.; Everts, K. L. Effect of Market Channel, Farm Scale, and Years in Production on mid-Atlantic Vegetable Producers' Knowledge and Implementation of Good Agricultural Practices. *Food Control.* 2016, *59*, 128–138. DOI: 10.1016/j.foodcont.2015.05.024.

[122] Hamilton, K. E.; Umber, J.; Hultberg, A.; Tong, C.; Schermann, M.; Diez-Gonzalez, F.; Bender, J. B. Validation of Good Agricultural Practices (GAP) on Minnesota Vegetable Farms. *Foodborne Pathogen Dis.* 2015, *12*(3), 145–150. DOI: 10.1089/fpd.2-14.1817.

[123] Ganpat, W.; Badrie, N.; Walter, S.; Roberts, L.; Nandlal, J.; Smith, N. Compliance with Good Agricultural Practices (Gaps) by State-registered and Non-registered Vegetable Farmers in Trinidad, West Indies. *Food Secur.* 2014, *6*(1), 61–69. DOI: 10.1007/s12571-013-0322-4.

[124] Rebouças, L. T.; Santiago, L. B.; Martins, L. S.; Menezes, A. C. R.; Araújo, M. P. N.; De Castro Almedia, R. C. Food Safety Knowledge and Practices of Food Handlers, Head Chefs and Managers in Hotels' Restaurants of Salvador, Brazil. *Food Control.* 2017, *73*, 372–381. DOI: 10.1016/j.foodcont.2016.08.026.

[125] Pichler, J.; Ziegler, J.; Aldrian, U.; Allerberger, F. Evaluating Levels of Knowledge on Food Safety among Food Handlers from Restaurants and Various Catering Businesses in Vienna, Austria 2011/2012. *Food Control.* 2014, *35*(1), 33–40. DOI: 10.1016/j.foodcont.2013.06.034.

[126] Nee, S. I.; Sani, N. A. Assessment of Knowledge. *Sains Malaysiana.* 2011, *40*(4), 403–410.

[127] Veiros, M. B.; Proença, R. P. C.; Santos, M. C. T.; Kent-Smith, L.; Rocha, A. Food Safety Practices in a Portuguese Canteen. *Food Control.* 2009, *20*(10), 936–941. DOI: 10.1016/j.foodcont.2009.02.002.

[128] Garayoa, R.; Vitas, A. I.; Díez-Leturia, M.; Garcia-Jalón, J.; Metzler, P.; Obwegeser, J. A. Food Safety and the Contract Catering Companies: Food Handlers, Facilities and HACCP Evaluation. *Food Control.* 2011, *22*(12), 2006–2012. DOI: 10.1097/SCS.0b013e31823197d8.

[129] Jena, G. B.; Chavan, S. Implementation of Good Laboratory Practices (GLP) in Basic Scientific Research: Translating the Concept beyond Regulatory Compliance. Regul. Toxicol. Pharmacol. 2017, 89, 20–25.

[130] Lepore, P. D.; Crawford, L. M. Regulation of Animal Care and Research. The Final Order on Good Laboratory Practices. *J. Anim. Sci.* 1981, *51*(2), 474–478. DOI: 10.2527/jas1980.512474x.

[131] Wolf, J. C.; Wolfe, M. J. Good Laboratory Practice Considerations in the Use of Fish Models. *Toxicol. Pathol.* 2003, *31*(Suppl.), 53–57. DOI: 10.1080/01926230390178739.

[132] Lucero, N. E.; Siñeriz, F. The Argentine Experience in Enhancing Biosafety through Good Laboratory Practices. *Asian Biotechnol. Develop. Rev.* 2005, *8*(1), 99–120.

[133] Hart, D. J.; John Scott, K. Development and Evaluation of an HPLC Method for the Analysis of Carotenoids in Foods, and the Measurement of the Carotenoid Content of Vegetables and Fruits Commonly Consumed in the UK. *Food Chem.* 1995, *54*(1), 101–111. DOI: 10.1016/0308-8146(95)92669-B.

[134] Allwood, P. A.; Jenkins, T.; Paulus, C.; Johnson, L.; Hedberg, C. W. Hand Washing Compliance among Retail Food Establishment Workers in Minnesota. *J. Food Prot.* 2004, *67*(12), 2825–2828. DOI: 10.4315/0362-028X-67.12.2825.

[135] Neal, J. A.; Binkley, M.; Henroid, D. Assessing Factors Contributing to Food Safety Culture in Retail Food Establishments. *Food Prot. Trends.* 2012, *32*(8), 468–476.

[136] Jame Wyatt, C.; Guy, V. Relationship of Microbial Quality of Retail Meat Samples and Sanitary Conditions. *J. Food Prot.* 1980, *43*(5), 385–389. DOI: 10.4315/0362-028X-43.5.385.

[137] Strohbehn, C.; Sneed, J.; Paez, P.; Meyer, J. Hand Washing Frequencies and Procedures Used in Retail Food Services. *J. Food Prot.* 2008, *71*(8), 1641–1650. DOI: 10.4315/0362-028X-71.8.1641.

[138] Picha, K.; Skořepa, L.; Navrátil, J. Assessment of the Results of the Strategic Orientation on Regional and Local Products in Food Retail. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis.* 2013, *61*(4), 1061–1068. DOI: 10.11118/actaun201361041061.

[139] Kungu, J. M.; Dione, M.; Roesel, K.; Ejobi, F.; Ocaido, M.; Grace, D. Assessment of Hygiene Practices of Pork Retail Outlets in Kampala District, Uganda. *Int. Food Res. J.* 2017, *24*(4), 1368–1373. 1985-4668.

[140] Ajani, E. N.; Onwubuya, E. A. Assessment of Use of Indigenous Maize Storage Practices among Farmers in Anambra State, Nigeria. *Int. J. Agric. Res. Innov. Technol.* 2012, *2*(2), 48–53. DOI: 10.3329/ijarit.v2i2.14014.

[141] Shabani, I.; Kimanya, M. E.; Gichuhi, P. N.; Bonsi, C.; Bovell-Benjamin, A. C. Maize Storage and Consumption Practices of Farmers in Handeni District, Tanzania. *Open J. Prev. Med.* 2015, *5*(8), 330–339. DOI: 10.4236/ojpm.2015.58037.

[142] Hell, K.; Cardwell, K. F.; Setamou, M.; Poehling, H.-M. The Influence of Storage Practices on Aflatoxin Contamination in Maize in Four Agroecological Zones of Benin, West Africa. *J. Stored Prod. Res.* 2000, *36*(4), 365–382. DOI: 10.1016/S0022-474X(99)00056-9.

[143] Katundu, M. G. C.; Hendriks, S. L.; Bower, J. P.; Siwela, M. Effects of Traditional Storage Practices of Small-scale Organic Farmers on Potato Quality. *J. Sci. Food Agric.* 2007, *87*(10), 1820–1825. DOI: 10.1002/jsfa.2861.

[144] Martins, W. S.; De Campos Leite, A. B.; Martins, R. L.; Da Silva, J. O.; De Carvalho Balian, S. Assessment of Frozen Seafood Good Storage Practices in the 21st Supply Deposit of the Brazilian Army. *Brazilian J. Veter. Res. Animal Sci.* 2019, *56*(2), e151385. DOI: 10.11606/.1678-4456.bjvras.2019.151385.

[145] Uplap, P. J.; Khandave, S. S.; Thorat, D. R.; Lohar, N. S. Knowledge and Adoption of Food Grain Storage Practices by Farm Women of Pune District (Maharashtra). *Agri. Update.* 2010, *5*(3 &4), 262–265.

[146] Evans, E. W.; Redmond, E. C. Older Adult Consumer Knowledge, Attitudes, and Self-reported Storage Practices of Ready-to-eat Food Products and Risks Associated with Listeriosis. *J. Food Prot.* 2016, *79*(2), 263–272. DOI: 10.4315/0362-028X.JFP-15-312.

[147] Balzan, S.; Fasolato, L.; Cardazzo, B.; Berti, G.; Novelli, E. Cold Chain and Consumers' Practices: Exploratory Results of Focus Group Interviews. *Italian J. Food Safety.* 2014, *3*(4). DOI: 10.4081/ijfs.2014.4516.

[148] Ackerley, N.; Sertkaya, A.; Lange, R. Food Transportation Safety: Characterizing Risks and Controls by Use of Expert. *Food Prot. Trends.* 2010, *30*(4), 212–222.

[149] Dewanti-Hariyadi, R.; (2009). Implementation of Food Safety Management at Industry Level in Developing Countries: Is GMP/HACCP Confusing? Proceeding of International Seminar Current Issues and Challenges in Food Safety. Science-based Approach for Food Safety Management, 2–3.

[150] Alimentarius, C.;. *Codex Alimentarius: HACCP System and Guidelines for Its Application. Food Hygiene Basic Texts*; FAO/WHO: Rome, 2011.

[151] Costa Dias, M. A.; Sant'Ana, A. S.; Cruz, A. G.; Faria, J.; De, A. F.; De Oliveira, C. A. F. On the Implementation of Good Manufacturing Practices in a Small Processing Unity of Mozzarella Cheese in Brazil. *Food Control.* 2012, *24* (1–2), 199–205. DOI: 10.1016/j.foodcont.2011.09.028.

[152] Rizvi, S. S. H.;. 2010. *Spearation, Extraction and Concentration Processes in the Food Beverage and Nutraceutical Industries.* Woodhead Publishing:694. ISBN: 978-1-84569-645-0

[153] Chin, R.; Lee, B. Y. *Principles and Practice of Clinical Trial Medicine* ISBN: 978-0-12-373695-6; Elsevier Academic Press: USA, 2008; pp 560.

[154] Nedovic, V.; Raspor, P.; Levic, J.; Saponjac, V. T.; Barbosa-Cánovas, G. V. 2016. *Emerging and Traditional Technologies for Safe, Healthy and Quality Food.* Switzerland. Springer International Publishing:487. ISBN 978-3-319-24038-1

[155] Sperber, W. H.;. Auditing and Verification of Food Safety and HACCP. *Food Control.* 1998, *9*(2–3), 157–162. DOI: 10.1016/S0956-9135(97)00068-6.

[156] Heredia, N.; Wesley, I.; Garcia, S. 2009. *Microbiologically Safe Foods.* Hoboken, NJ-USA. John Wiley & Sons:572. ISBN: 978-0-470-05333-1

[157] Lockis, V. R.; Cruz, A. G.; Walter, E. H. M.; Faria, J. A. F.; Granato, D.; Sant'Ana, A. S. Prerequisite Programs at Schools: Diagnosis and Economic Evaluation. *Foodborne Pathogens Dis.* 2011, *8*(2), 213–220. DOI: 10.1089/fpd.2010.0645.

[158] Ababio, P. F.; Taylor, K. D. A.; Swainson, M.; Daramola, B. A. Effect of Good Hygiene Practices Intervention on Food Safety in Senior Secondary Schools in Ghana. *Food Control.* 2016a, *6*, 18–24. DOI: 10.1016/j.foodcont.2015.07.013.

[159] Lelieveld, H. L. M.; Mostert, M. A.; Holah, J.; White, B. *Hygiene in Food Processing. Cambridge*; Woodhead Publishing Ltd.: England, 2003; ISBN 1855734664. Vol. 390.

[160] Raspor, P.; Ambrožič, M.; Jevšnik, M. Food Chain Safety Management Systems: The Impact of Good Practices. *Advances in Food Process Engineering Research and Applications.* Yanniotis, S. et al.,eds. Food Engineering Series: New York, 2013, pp. 19. 10.1007/978-1-4614-7906-230

[161] Langiano, E.; Ferrara, M.; Lanni, L.; Viscardi, V.; Abbatecola, A. M.; De Vito, E. Food Safety at Home: Knowledge and Practices of Consumers. *J. Public Health.* 2012, *20*(1), 47–57. DOI: 10.1007/s10389-011-0437-z.

[162] Bhat, R.; Alias, A. K.; Paliyath, G.,Eds. 2012. *Progress in Food Preservation.* Wst Sussex, UK:Wiley-Blackwell. 633. ISBN: 978-0-470-65585-6

[163] Ababio, P. F.; Taylor, K. D. A.; Daramola, B. A.; Swainson, M. Food Law Compliance in Developed and Developing Countries: Comparing School Kitchens in Lincolnshire-UK and Ashanti Region of Ghana. *Food Control.* 2016b, *68*, 167–173. DOI: 10.1016/j.foodcont.2016.03.023.

[164] Herschdoerfer, S. M.;. *Quality Control in the Food Industry*; Academic Press: London UK, 1968; LCCN: 67-19849. Vol. 2.

[165] Ponte, S.;. Bans, Test and Alchemy: Food Safety Regulation and the Uganda Fish Export Industry. *Agri. Hum. Values.* 2007, *24*(2), 179–193. DOI: 10.1007/S10460-006-9046-9.

[166] Wallace, C. A.; Sperber, W. H.; Mortimore, S. C. *Food Safety for the 21st Century: Managing HAPP and Food Safety Throughout the Global Supply Chain*, 2nd Edition; John Wiley and Sons, Ltd.: Oxford, UK, 2018. pp. 494. ISBN: 978111905383.

[167] Som, S.; (2015). Designing E-learning Module on Good Agricultural Practices (GAP) for Grapes. MSc Thesis, Indian Agricultural Research Institute, New Delhi, India, pp. 157.

[168] Nayak, R.; (2016). Implementation of Good Agricultural Practices Food Safety Standards on Mid-Atlantic States and New York Produce Farms. PhD Thesis, Graduate School Department of Agricultural Economics, Sociology and Education, The Pennsylvania State University, pp. 219.

[169] Burrell, A.;. Good Agricultural Practices in the Agri-Food Supply Chain. *Environ. Law Rev.* 2011, *13*(4), 251–270. DOI: 10.1350/enlr.2011.13.4.251.

[170] De Quadros Rodrigues, R.; Loiko, M. R.; Daniel De Paula, C. M.; Hessel, C. T.; Jacxsens, L.; Uyttendaele, M.; Bender, R. J.; Tondo, E. C. Microbiological Contamination Linled to Implementation of Good Agricultural Practices in the Production of Organic Lettuce in Southern Brazil. *Food Control.* 2014, *42*, 152–164. DOI: 10.1016/j.foodcont.2014.01.043.

[171] Bartz, S.; Hessel, C. T.; De Quadros Rodrigues, R.; Possamai, A.; Perini, F. O.; Jacxsens, L.; Uyttendaele, M.; Bender, R. J.; Tondo, E. C. Insights in Agricultural Practices and Management Systems Linked to Microbiological Contamination of Lettuce in Conventional Production Systems in Southern Brazil. *Int. J. Food Contamin.* 2015, *2* (1), 7. DOI: 10.1186/s40550-015-0011-5.

[172] Good Storage Practices, https://minpharmum.files.wordpress.com/2011/09/gsp.pdf, Accessed 17 May 2020.

[173] Good Catering Practices (GCP) – King Cert (http://kingcert.com/standardlar/food-certification/gcp-good-catering-practices/en/) Accessed 05 March 2020, 13.06 h GMT.

[174] Good Certification Practice Audits. Intertek (http://www.intertek.com/food/good-catering-practices/) Accessed 05 March 2020, 13.46 h GMT.

[175] Berker, R. A.; Janus, E. R.; White, R. D.; Kruszewsk, F. H.; Brackett, R. E. Good Laboratory Practices and Safety Assessments. *Environ. Health Perspect.* 2009, *117*(11), A482–A483. DOI: 10.1289/ehp.0900884.

[176] Shukla, S.; Shankar, R.; Singh, S. P. Food Safety Regulatory Model in India. *Food Control.* 2014, *37*, 401–413. DOI: 10.1016/j.foodcont.2013.08.015.

[177] Laurison, H.; Young, N. (2009). Oakland Food Retail Impact Study. In: FoodFirst Development Report No. 20. Theme 'Ending Injustices That Cause Hunger and Environmental Destruction'. Institute for Food and Development Policy, Oakland, CA-USA, pp. 33, http://community.wealth.org/sites/done.community-wealth.org/files/downloads/paper-laurison-young.pdf/ Accessed 13 March 2020, 13.54h GMT

[178] Ilbery, B.; Maye, D. Retailing Local Food in the Scottish-English Borders: A Supply Chain Perspective. *Geoforum.* 2006, *37*(3), 352–367. DOI: 10.1016/j.geoforum.2005.09.003.

[179] Gole, S.; (2018). Unit-14: Good Retail Practices, Good Transport Practices, and Nutrition Labelling. IGNOU. http://egyankosh.ac.in//handle/123456789/42855, Accessed 6 April 2021.

[180] Ryan, J.;. *Guide to Food Safety and Quality during Transportation: Controls, Standards and Practices* ISBN: 9780128121405; Academic Press: London, UK, 2017; pp 342.

[181] Peters, R. E.;. The Broader Application of HACCP Concepts to Food Quality in Australia. *Food Control.* 1998, *9* (2–3), 83–89. DOI: 10.1016/S0956-7135(97)00078-9.

[182] Kołożyn-Krajewska, D.; Sikora, T. *HACCP. Koncepcja I System Zapewnienia Bezpieczeństwa Jakości*; Warszawa: SITSpoż, 1999.

[183] Bennet, W. L.; Steed, L. L. An Integrated Approach to Food Quality. *Qual. Progr.* 1999, *32*, 37–42.

[184] Bernard, D.;. Developing and Implementing HACCP in the USA. *Food Control.* 1998, *9*(2–3), 91–95. DOI: 10.1016/S0956-7135(97)00056-X.

[185] Baş, M.; Yüksel, M.; Çavuşoğlu, T. Difficulties and Barriers for the Implementing of HACCP and Food Safety in Food Businesses in Turkey. *Food Control.* 2007, *18*(2), 124–130. DOI: 10.1016/j.foodcont.2005.09.002.

[186] Mayes, T.; Mortimore, S. *Making the Most of HACCP: Learning from Others' Experience*; Woodhead Publishing Ltd: England, UK, 2001; ISBN: 978-0849312182. Vol. 320.

[187] Buchanan, R. L.; Whiting, R. C. Risk Assessment: A Means for Linking HACCP Plans and Public Health. *J. Food Prot.* 1988, *6*(11), 1531–1534.

[188] Ying, Z. Q.; Zhimin, C. HACCP and the Risk Assessment of Cold Chain. *I.J. Wireless Microwave Technol.* 2011, *1* (1), 67–71. DOI: 10.5815/ijwmt.2011.01.10.

[189] Latronico, F.; Correia, S.; De Silva Felicio, T.; Hempen, M.; Messens, W.; Ortiz-Pelaez, A.; Stella, P.; Liebana, E.; Hugas, M. Challenges and Prospects of the European Food Safety Authority Biological Hazards Risk Assessments for Food Safety. *Curr. Opin. Food Sci.* 2017, *18*, 50–55.

[190] Trafiałek, J.; Kolanowski, W. Implementation and Functioning of HACCP Principles in Certified and Non-certified Food Businesses. *Br. Food J.* 2017, *119*(4), 710–728. DOI: 10.1108/BFJ-07-2016-0313.

[191] Tomasevic, I.; Kuzmanović, J.; Anctelković, A.; Saračević, M.; Stojanović, M. M.; Djekic, I. The Effects of Mandatory HACCP Implementation on Microbiological Indicators of Process Hygiene in Meat Processing and Retail Establishments in Serbia. *Meat Sci.* 2016, *114*, 54–57. DOI: 10.1016/j.meatsci.2015.12.008.

[192] Trafiałek, J.; Lehrke, M.; Lücke, F. K.; Kołożyn-Krajewska, D.; Janssen, J. HaCCP-based Procedures in Germany and Poland. *Food Control.* 2015, *55*, 66–74. DOI: 10.1016/j.foodcont.2015.01.031.

[193] Dzwolak, W.;. HACCP in Small Food Businesses – The Polish Experience. *Food Control.* 2014, *36*(1), 132–137. DOI: 10.1016/j.foodcont.2013.07.043.

[194] Baek, S.-H.; Kang, S.-C.; Lee, W.-C.; Nam, I.-S. Effects of HACCP System Implementation on Domestic Livestock Product Plants. *Korean Journal for Food Science of Animal Resources*. 2012, *32*(2), 168–173. DOI: 10.5851/kosfa.2012.32.2.168.

[195] Shih, K. M.; Wang, W. K. Factors Influencing HACCP Implementation in Taiwanese Public Hospital Kitchens. *Food Control*. 2011, *22*(3–4), 496–500. DOI: 10.1016/j.foodcont.2010.09.034.

[196] Kokkinakis, E. N.; Kokkinaki, A. N.; Kyriakidis, G.; Markaki, A.; Fragkiadakis, G. A. HACCP Implementation in Local Food Industry: A Survey in Crete, Greece. *Procedia Food Sci.* 2011, *1*, 1079–1083. DOI: 10.1016/j.profood.2011.09.161.

[197] Lupin, H. M.; Parin, M. A.; Zugarramurdi, A. HACCP Economics in Fish Processing Plants. *Food Control*. 2010, *21*(8), 1143–1149. DOI: 10.1016/j.foodcont.2010.01.009.

[198] Kök, M. S.;. Application of Food Safety Management Systems (ISO22000/HACCP) in the Turkish Poultry: A Comparison Based on Enterprise Size. *J. Food Prot.* 2009, *72*(10), 2221–2225. DOI: 10.4315/0362-028X-72.10.2221.

[199] Kokkinakis, E. N.; Fragkiadakis, G. A.; Ioakeimidi, S. H.; Giankoulof, I. B.; Kokkinaki, A. N. Microbiological Quality of Ice-cream before and after HACCP Implementation: A Factory Case Study. *Czech J. Food Sci.* 2008, *26*(5), 383–391. DOI: 10.17221/1126-CJFS.

[200] Semos, A.; Kontogeorgos, A. HACCP Implementation in Northern Greece. *Br. Food J.* 2007, *109*(1), 5–19. DOI: 10.1108/00070700710718471.

[201] Celaya, C.; Zabala, S. M.; Pérez, P.; Medina, J.; Mañas, J.; Fouz, J.; Alonso, A.; Antón, A.; Agundo, N. The HACCP System Implementation in Small Businesses of Madrid's Community. *Food Control*. 2007, *18*(10), 1314–1321.

[202] Khatri, Y.; Collins, R. Impact and Status of HACCP in the Australian Meat Industry. *Br. Food J.* 2007, *109*(5), 343–354. DOI: 10.1108/00070700710746768.

[203] Bai, L.; Ma, C. L.; Yang, Y. S.; Zhao, S. K.; Gong, S. L. Implementation of HACCP System in China: A Survey of Food Enterprises Involved. *Food Control*. 2007, *18*(9), 1108–1112. DOI: 10.1016/j.foodcont.2006.07.006.

[204] Baş, M.; Ersun, A. S.; Kivanç, G. Implementation of HACCP and Prerequisite Programs in Food Businesses in Turkey. *Food Control*. 2006, *17*(2), 118–126. DOI: 10.1016/j.foodcont.2004.09.010.

[205] Fielding, L. M.; Ellis, L.; Beveridge, C.; Peters, A. C. An Evaluation of HACCP Implementation Status in UK Small and Medium Enterpises in Food Manufacturing. *Int. J. Environ. Health Res.* 2005, *15*(2), 117–126. DOI: 10.1080/09603120500061583.

[206] Maldonado, E. S.; Henson, S. J.; Caswell, J. A.; Leos, L. A.; Martinez, P. A.; Aranda, G.; Cadena, J. A. Cost-benefit Analysis of HACCP Implementation in the Mexican Meat Industry. *Food Control*. 2005, *16*(4), 375–381. DOI: 10.1016/j.foodcont.2004.03.017.

[207] Youn, S.; Sneed, J. Implementation of HACCP and Prerequisite Programs in School Foodservice. *J. Am. Diet. Assoc.* 2003, *103*(1), 55–60. DOI: 10.1053/jada.2003.50002.

[208] Worsfold, D.; Griffith, C. J. Widening HACCP Implementation in the Catering Industry. *Food Serv. Technol.* 2003, *3*(3–4), 113–122. DOI: 10.1111/j.1471-5740.2003.00075.x.

[209] Walker, E.; Pritchard, C.; Forsythe, S. Hazard Analysis Critical Control Point and Prerequisite Programme Implementation in Small and Medium Size Food Businesses. *Food Control*. 2003, *14*(3), 169–174. DOI: 10.1016/S0956-7135(02)00061-0.

[210] Nam, E. J.; Kim, M.; Lee, Y. K. Effects of HACCP Implementation on an Industry Foodservice Operation in Daegu. *Korean J. Nutri.* 2003, *36*(2), 223–230.

[211] Henson, S.; Holt, G. Exploring Incentives for the Adoption of Food Safety Controls: HACCP Implementation in the UK Dairy Sector. *Rev. Agric. Econ.* 2000, *22*(2), 407–420. DOI: 10.1111/1058-7195.00030.

[212] Panisello, P. J.; Quantick, P. C.; Knowles, M. J. Towards the Implementation of HACCP: Results of a UK Regional Survey. *Food Control*. 1999, *10*(2), 87–98. DOI: 10.1016/S0956-7135(98)00161-3.

[213] Ehiri, J. E.; Morris, G. P.; McEwen, J. A Survey of HACCP Implementation in Glasgow: Is the Information Reaching the Target? *Int. J. Environ. Health Res.* 1997, *7*(1), 71–84. DOI: 10.1080/09603129774020.

[214] Arvanitoyannis, I. S.; Varzakas, T. H. Application of ISO 22000 and Comparison with HACCP on Industrial Processing of Common Octopus (*Octopus Vulgaris*) - Part I. *Int. J. Food Sci. Technol.* 2009, *44*(1), 58–78. DOI: 10.1111/j.1365-2621.2007.01666.x.

[215] Aung, M. M.; Chang, Y. S. Traceability in a Food Supply Chain: Safety and Quality Perspectives. *Food Control*. 2014, *39*, 172–184. DOI: 10.1016/j.foodcont.2013.11.007.

[216] Ziggers, G. W.; Trienekens, J. Quality Assurance in Food and Agribusiness Supply Chains: Developing Successful Partnerships. *Int. J. Production Econ.* 1999, *60-61*, 271–279. DOI: 10.1016/S0925-5273(98)00138-8.

[217] Holleran, E.; Bredahl, M. E.; Zaibet, L. Private Incentives for Adopting Food Safety and Quality Assurance. *Food Policy*. 1999, *24*(6), 669–683. DOI: 10.1016/S0306-9192(99)00071-8.

[218] Alsaleh, N. A.;. Application of Quality Tools by the Saudi Food Industry. *TQM Mag.* 2007, *19*(2), 150–161. DOI: 10.1108/09544780710729999.

[219] Wilcock, A. E.; Boys, K. A. Improving Quality Management: ISO 9001 Benefits for Agrofood Firms. *J. Agribusiness Develop. Emerg. Econ.* 2017, *7*(1), 2–20. DOI: 10.1108/JADEE-12-2014-0046.

[220] Blanc, D.; (2006). ISO22000. From Intent to Implementation. ISO Management Systems, pp. 7–11, www.iso.org/ims,http://www.efrcertification.com/news%20file/22000_implementation_ims_06_03.pdf, Accessed 31 May 2021.
[221] Surak, J. G.;. A Recipe for Safe Food: ISO22000 & HACCP. *Qual. Progr.* 2007, *40*(10), 21–27.
[222] Mamalis, S.; Kafetzopoulos, D. P.; Aggelopoulos, S. (2009). The New Food Safety Standard ISO22000. Assessment, Comparison and Correlation with HACCP and ISO9000:2000. The Practical Implementation in Victual Business. Presentation at the 113th EAAE Seminar 'A resilient European food industry and food chain in a challenging world", Chania, Crete – Greece, September 3-6, 2009.
[223] Conde, G. J.; López-Valeiras Sampedro, E.; Feliu, V. R.; Sànchez, M. B. G. Management Control Systems and ISO Certification as Resources to Enhance Internationalization and Their Effect on Organizational Performance. *Agribusiness.* 2013, *29*(3), 392–405. DOI: 10.1002/agr.21300.
[224] Feng, M.; Terziovski, M.; Samson, D. Relationship of ISO 9001: 2000quality System Certification with Operational and Business Performance: A Survey in Australia and New Zealand-based Manufacturing and Service Companies. *J. Manuf. Tech. Manag.* 2008, *19*(1), 22–37. DOI: 10.1108/17410380810843435.
[225] Vesna, P.; Predrag, V.; Milivoje, Ć. Food Safety and Quality Policy in the Republic of Serbia. *Econ. Agric.* 2017, *4* (64), 1607–1617.
[226] Guoa, Z.; Baia, L.; Gong, S. Government Regulations and Voluntary Certifications in Food Safety in China: A Review. *Trends Food Sci. Technol.* 2019, *90*, 160–165. DOI: 10.1016/j.tifs.2019.04.014.
[227] ISO survey. 2019. International Organization for Standardization. https://www.iso.org/home.html. Accessed 06 April 2021
[228] Weyandt, A. J.; Reis Da Costa, S. R.; Nunes, M. L.; Gaspar, A. Environmental & Food Safety Management Systems, according to ISO 14001 & ISO 22000 in Fish Processing Plants: Experiences, Critical Factors & Possible Future Strategies. *Procedia Food Sci.* 2011, *1*, 1901–1906. DOI: 10.1016/j.profoo.2011.09.279.
[229] Escanciano, C.; Santos-Vijande, M. L. Reasons and Constraints to Implementing an ISO 22000 Food Safety Management System: Evidence from Spain. *Food Control.* 2014, *40*, 50–57. DOI: 10.1016/j.foodcont.2013.11.032.
[230] Van Der Spiegel, M.; Van Der Fels-klerx, H. J.; Sterrenburg, P.; Van Ruth, S. M.; Scholtens-Toma, I. M. J.; Kok, E. J. Halal Assurance in Food Supply Chains: Verification of Halal Certificates Using Audits and Laboratory Analysis. *Trends Food Sci. Technol.* 2012, *27*(2), 109–119. DOI: 10.1016/j.tifs.2012.04.005.
[231] Regenstein, J. M.; Chaudry, M. M.; Regenstein, C. E. The Kosher and Halal Food Laws. *Compr. Rev. Food Sci. Food Saf.* 2003, *2*(3), 111–127. DOI: 10.1111/j.1541-4337.2003.tb00018.x.
[232] Bonne, K.; Verbeke, W. Religious Values Informing Halal Meat Production and the Control and Delivery of Halal Credence Quality. *Agri. Hum. Values.* 2008, *25*(1), 35–47. DOI: 10.1007/s10460-007-9076-y.
[233] Soon, J. M.; Chandia, M.; Regenstein, J. M. Halal Integrity in the Food Supply Chain. *Br. Food J.* 2017, *119*(1), 39–51. DOI: 10.1108/BFJ-04-2016-0150.
[234] Corte, V. D.; Del Gaudio, G.; Sepe, F. Ethical Food and the Kosher Certification: A Literature Review. *Br. Food J.* 2018, *120*(10), 2270–2288. DOI: 10.1108/BFJ-09-2017-0538.
[235] Regenstein, J. M.; Chaudry, M. M. (2001). A Brief Introduction to Some of the Practical Aspects of the Kosher and Halal Laws for the Poultry Industry. (Chapter 16). In *Poultry Meat Processing*, Sam, A.R. (ed.). Florida, USA: CRC Press, pp. 281–300, ISBN: 978-0-8493-0120-9.
[236] Blech, Z. Y.;. 2008. *Kosher Food Production*. Iowa, USA. John Wiley & Sons:528. ISBN: 978-0-813-82093-4
[237] Sullivan, C. B.; (1993). Are Kosher Food Laws Constitutionally Kosher? 21 Boston College Environmental Affairs Law Review 201, pp. 1–46, http://lawdigitalcommons.bc.edu/ealr/vol21/iss1/5, Accessed 11 May 2020.
[238] Bendell, T.; Kelly, J.; Merry, T.; Sims, F. *Quality: Measuring and Monitoring (The Sunday Times Business Skills Series)* ISBN: 071265514X; Century Business: London, UK, 1993; pp 303.
[239] Westgard, J. O.; Barry, P. L. *Cost-effective Quality Control: Managing the Quality and Productivity of Analytical Processes*; AACC Press: Washington DC, 1997.
[240] Early, R.;. *Guide to Quality Management Systems for the Food Industry* ISBN 0751401668; Blackie Academic & Professional Publishers: Glasgow UK, 1995; pp 308.
[241] Aggelogiannopoulos, D.; Drossinos, E. H.; Athanasopoulos, P. Implementation of A Quality Management System according to the ISO 9000family in A Greek Small-sized Winery: A Case Study. *Food Control.* 2007, *18*(9), 1077–1085. DOI: 10.1016/j.foodcont.2006.07.010.
[242] Lo, V.; Humphreys, P. Project Management Benchmarks for SMEs Implementing ISO. *Benchmarking Int. J.* 2000, *7*(4), 247–259. DOI: 10.1108/14635770010378891.
[243] Rodrìnges-Escobar, J. A.; Gonzalez-Benito, J.; Martìnez-Lorente, A. R. Ananalysis of the Degree of Small Companies' Dissatisfaction with ISO 9000certification.Total. *Qual. Manag.* 2006, *17*(4), 507–521.
[244] Gotzamani, K.; Tsiotras, G. C. The True Benefits behind ISO 9000certification: Their Effect on the Overall Certification Benefits and Long Termcontribution Towards. *International Journal of Quality & Reliability Management.* 2002, *19*(2), 151–169. DOI: 10.1108/02656710210413499.
[245] Adair, J. E.;. *Understanding Motivation* ISBN: 9780951183588; Talbot Adair Press: Guildford, 1990; pp 114.
[246] Belbin, R. M. Team Roles at Work, 2nd Revised ed.; Routledge, Taylor & Francis Group: Oxford, UK, 2017. ISBN: 9781138433199

[247] Briscoe, J. A.; Fawcett, S. E.; Todd, R. H. The Implementation and Impact ofISO 9000 among Small Manufacturing Enterprises. *J. Small Business Manag.* 2005, *43*(3), 309–330. DOI: 10.1111/j.1540-627X.2005.00139.x.

[248] Poksinska, B.; Jörn Dahlgaard, J.; Eklund, J. A. E. ISO 9001: 2000in Smallorganisations: Lost Opportunities, Benefits and Influencing Factors. *Int. J. Qual. Reliab. Manag.* 2004, *23*(5), 490–512. DOI: 10.1108/02656710610664578.

[249] Poksinska, B.; Jörn Dahlgaard, J.; Eklund, J. A. E. From Compliance to Valueadded Auditing: Experiences from a Swedish ISO 9001: 2000certifiedorganisation.Total. *Qual. Manag.* 2006, *17*(7), 879–892.

[250] Solis, L. E.; Rao, S. S.; Ragu-Nathan, T. S. The Best Quality Managementpractices in Small and Medium Enterprises: An International Study. *Int. J. Manuf. Technol. Manag.* 2001, *3*(4/5), 416–443. DOI: 10.1504/IJMTM.2001.001421.

[251] Van Der Wiele, T.; Van Iwaarden, J.; Williams, R.; Dale, B. Perceptions Aboutthe ISO 9000 (2000) Quality System Standard Revision and Its Value: The Dutchexperience.International. *International Journal of Quality & Reliability Management.* 2005, *22*(2), 101–119. DOI: 10.1108/02656710510577189.

[252] Brown, A.; Van Der Wiele, T.; Loughton, K. Smaller Enterprises' Experienceswith ISO 9000. *Int. J. Qual. Reliab. Manag.* 1998, *15*(3), 273–285. DOI: 10.1108/02656719810198935.

[253] Noci, G.;. Accounting and Non-accounting Measures of Quality-basedperformances in Small Firms. *Int. J. Oper. Prod. Manag.* 1995, *15*(7), 78–105. DOI: 10.1108/01443579510090435.

[254] Noci, G.; Toletti, G. A Decision Support System for the Selection of Quality-based Programs in Small Firms. *Manag. Decision.* 1998, *36*(7), 473–486. DOI: 10.1108/00251749810227057.

[255] Capmany, C.;. ISO 9000 – Amarketing Tool for Agribusiness. *The International Food and Agribusiness Management Review.* 2000, 3(1), 41–53. DOI: 10.1016/S1096-7508(00)00027-6.

[256] Rahman, S.;. A Comparative Study of TQM Practice and Organisationalperformance of SMEs with and without ISO 9000 Certification. *Int. J. Qual. Reliab. Manag.* 2001, *18*(1), 25–49.

[257] Paiva, C. L. Quality Management: Important Aspects for the Food Industry. In *Food Industry,*Muzzalupo, I., Ed.; London, UK: *INTECH Open*; Chapter 2013; Vol. 9,1–29.https://www.intechopen.com/books/food-industry/quality-management-important-aspects-for-the-food-industry Accessed 15 March 2021.10.5772/53162

[258] The Different Types of Benchmarking – Examples and Easy Explanations (www.bernardmarr.com/default.asp?contentID=1753; Accessed 23/01/2020, 23.15 h GMT)

[259] What Is Benchmarking? www.shopify.com/encyclopedia/benchmarking, Accessed 23/01/2020, 20.12 h GMT

[260] Beeler, G. W.;. HLTVersion3 – An Object-oriented Methodology for Collaborative Standards Development 1. Presented at the International Medical Informatics Association Working Group 16 Conference on Standardization in Medical Informatics – Towards International Consensus and Cooperation, Bermuda, 12 September 1997. *Int. J. Med. Inform.* 1998, *48*, 151. DOI: 10.1016/S1386-5056(97)00121-4.

[261] Pelkmans, J.;. The New Approach to Technical Harmonization and Standardization. *JCMS.* 1987, *25*(3), 249. DOI: 10.1111/j.1468-5965.1987.tb00294.x.

[262] Dreusch, A. B.;. *ISO22000: 2005 – Pracktische Umsetzung des globalen Zertifizierungsstandards für die gesamte Lebensmittelkette*; Behr's Verlag: Hamburg, 2006.

[263] Luning, P. A.; Marcelis, W. J.; Jongen, W. M. F. *Food Quality Management: A Techno-Managerial Approach* ISBN 9074134815; Wageningen Pers Publishers: Wageningen, Netherlands, 2002; pp 323.

[264] Mazé, A.; Ait-Aissa, M.; Verjux, N.; Carrotte, G.; Hédouin, C.; Vaucelle, A. *Audit Regulation and the Improvement of Benchmarking Procedures among Quality Assurance Schemes in Agriculture*; Published by EAAE-Proceeding Band von der EAAR-Koferenz vom 2.3. – 4. 3.2005 in Göttingen: Germany, 2006.

[265] Kher, S. V.; Frewer, J. D.; De Jonge, J.; Wentholt, M.; Davies, O. H.; Lucas Luijckx, N. B.; Cnossen, H. J. Experts' Perspectives on the Implementation of Traceability in Europe. *Br. Food J.* 2010, *112*(3), 261–274. DOI: 10.1108/00070701011029138.

[266] Regatteri, A.; Gamberi, M.; Manzini, R. Traceability of Food Products: General Framework and Experimental Evidence. *J. Food Eng.* 2007, *81*(2), 347–356. DOI: 10.1016/j.jfoodeng.2006.10.032.

[267] De Frahan, B. H.; Vancauteren, M. Harmonisation Trade in the Single Market: Evidence from Disaggregated Data. *Eur. Rev. Agri. Econ.* 2006, *33*(3), 337–360. DOI: 10.1093/eurrag/jbl015.

[268] Henson, S.; Humphery, J. (2009). The Impact of Private Food Safety Standards on the Food Chain and on Public Standard Setting Processes. Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission, 32nd session, FAO Headquarters, Rome, 29 June – 4 July 2009.

[269] Aramyan, L.; Ondersteijn, C. J. M.; Van Kooten, O.; Lansink, A. O. Performance Indicators in Agri-Food Production Chains. In *Quantifying the Agri-food Supply Chain*; Ondersteijn, C.J.M., Wijnands, J.H.M., Huirne, R.B.M., van Kooten, O., Eds.; Springer: Netherlands, 2006; pp. 47–64.

[270] Jongen, W. M. F.;. Food Supply Chains: From Productivity toward Quality. In *Fruit & Vegetable Quality: An Integrated View*; Shewfelt, R.L., Brückner, B., Eds.; Technomic: Lancaster, 2000; pp 3–18.

[271] Northen, J. R.;. Quality Attributes and Quality Cues: Effective Communication in the UK Meat Supply Chain. *Br. Food J.* 2000, *102*(3), 230–245. DOI: 10.1108/00070700010324727.

[272] Dickinson, D. L.; Bailey, D. Meat Traceability: Are U.S. Consumers Willing to Pay for It? *J. Agric. Res. Econ.* 2002, *27*, 348–364. www.jstor.org/stable/40987840.

[273] Fearne, A.;. The Evolution of Partnerships in the Meat Supply Chain: Insights from British Beef Industry. *Supply Chain Manag. Int. J.* 1998, *3*(4), 214–231. DOI: 10.1108/13598549810244296.

[274] Vasconcellos, J. A.;. *Quality Assurance for the Food Industry: A Practical Approach* ISBN 0-8493-1912-9; CRC Press: New York, USA, 2005; pp 421.

[275] Okpala, C. O. R.; Nwobi, O. C.; Korzeniowska, M. Towards Delineating Butchers' Knowledge Base, Challenges Encountered, and Enhancement Prospects of Meat Inspection Processes: A Cattle Slaughterhouse Case Analysis. *Meat Technol.* 2021b, *62*(1), 41-56

[276] Fotopoulos, C.; Kafetzopoulos, D.; Gotzamani, K. Critical Factors for Effective Implementation of the HACCP System: A Pareto Analysis. *Br. Food J.* 2011, *113*(5), 578–597. DOI: 10.1108/00070701111131700.

[277] BIOHAZ - EFSA Panel on Biological Hazards. 2018. Hazard Analysis Approaches for Certain Small Retail Establishments and Food Donations: Second Scientific Opinion. *EFSA J.* *16*(11). 5432. 52. 10.2903/j.efsa.2018.5432

[278] BIOHAZ - EFSA Panel on Biological Hazards. 2017. Hazard Analysis Approaches for Certain Small Retail Establishments in View of the Application of Their Food Safety Management Systems. *EFSA J.* *15*(3). 4697. 52. 10.2903/j.efsa.2017.4697

[279] Lund, B. M.; Baird-Parker, A. C.; Gould, G. W. (Eds). *Microbiological Safety and Quality of Food*; Aspen Publishers, Inc.: Maryland, USA, ISBN 0-8342-1323-0, 2000; pp 2024.

[280] Racicot, M.; Zanabria, R.; Paradis, M. È.; Gaucher, M. L.; Arsenault, J.; Leroux, A.; Letellier, A.; Tiwari, A.; Griffiths, M.; Charlebois, S.;; et al. Identification of Risk Factors to Be Considered for Food Establishments' Risk Assessment Models. *Microbial Risk Anal.* 2019, *11*, 1–10. DOI: 10.1016/j.mran.2018.01.004.

[281] Manning, L.; Soon, J. M. Food Safety. *J. Food Sci.* 2016, *81*(4), R823–R834.

[282] Okpala, C. O. R.;. Towards Enhancing the Detection of Adulteration in Bioactive Food Products. *J. Food Bioactives.* 2019, *6*, 6–9. DOI: 10.31665/JFB.2019.6183.

[283] Varzakas, T. H.; Arvanitoyannis, I. S. Application of Failure Mode and Effect Analysis (FMEA), Cause and Effect Analysis, and Pareto Diagram in Conjunction with HACCP to a Corn Curl Manufacturing Plant. *Crit. Rev. Food Sci. Nutr.* 2007, *47*(4), 363–387. DOI: 10.1080/10408390600781316.

[284] Varzakas, T. H.; Arvanitoyannis, I. S. Application of Failure Mode and Effect Analysis (FMEA) and Cause and Effect Analysis in Conjunction with ISO 22000 to A Snails (*Helix Aspersa*) Processing Plants; A Case Study. *Crit. Rev. Food Sci. Nutr.* 2009, *49*(7), 607–625. DOI: 10.1080/10408390802145294.

[285] Varzakas, T. H.;. Application of ISO22000, Failure Mode and Effect Analysis (FMEA) and Cause and Effect Analysis and Pareto in Conjunction with HACCP and Risk Assessment for Processing of Pastry Products. *Crit. Rev. Food Sci. Nutr.* 2011, *51*(8), 762–782. DOI: 10.1080/10408391003799970.

[286] Lammerding, A. M.; Fazil, A. Hazard Identification and Exposure Assessment for Microbial Food Safety Risk Assessment. *Int. J. Food Microbiol.* 2000, *58*(3), 147–157. DOI: 10.1016/S0168-1605(00)00269-5.

[287] Buchanan, R. L.; Smith, J. L.; Long, W. Microbial Risk Assessment: Dose-response Relations and Risk Characterization. *Int. J. Food Microbiol.* 2000, *58*(3), 159–172. DOI: 10.1016/S0168-1605(00)00270-1.

[288] Swanson, K. M. J.; Anderson, J. E. Industry Perspectives on the Use of Microbial Data for Hazard Analysis and Critical Control Point Validation and Verification. *J. Food Prot.* 2000, *63*(6), 815–818. DOI: 10.4315/0362-028X-63.6.815.

[289] Taverniers, I.; De Loose, M.; Van Bockstaele, E. Trends in Quality in the Analytical Laboratory. II. Analytical Method Validation and Quality Assurance. *TrAC Trends Anal. Chem.* 2004, *23*(8), 535–552. DOI: 10.1016/j.trac.2004.04.001uy.

[290] Casolani, N.; Liberatore, L.; Psomas, E. Implementation of Quality Management System with ISO 22000 in Food Italian Companies. *Qual. Access Success.* 2018, *19*(165), 125–131.

[291] Driscoll, B.;. Internal Audits Create Opportunity for Food Organizations Toimprove Sytems. *Food Qual. Safety.* 2012. Available from:http://www.foodqualityandsafety.com/article/internal-audits-create-opportunity-for-food-organizations-to-improve-systems-processes/.Accessed ().

[292] GFSR. 2016. Food Safety Audits. Available from:http://globalfoodsafetyresource.com/food-safety/food-safety-audits#, Accessed 6 April 2021.

[293] Djekic, I.; Tomasevic, I.; Radovanovic, R. Quality and Food Safety Issues Revealed in Certified Food Companies in Three Western Balkans Countries. *Food Control.* 2011), *22*(11), 1736–1741. DOI: 10.1016/j.foodcont.2011.04.006.

[294] Losito, P.; Visciano, P.; Genualdo, M.; Cardone, G.; Frank, V.; Fehrenbach, H.; Hampel, T.; Pape, L.; Buske, A.; Jonsson, J. Food Supplier Qualification by an Italian Large-scale-Distributor: Auditing System and Non-conformances Food Control. *Journal of the American Society of Nephrology : JASN.* 2011, *22*(12), 2047–2051. DOI: 10.1681/ASN.2010101080.

[295] Djekic, I.; Dragojlovic, S.; Miloradovic, Z.; Miljkovic-Zivanovic, S.; Savic, M.; Kekic, V.; Griffith, C.; Griffith, C. Improving the Confectionary Industry Supply Chain through Second Party Audits. *Br. Food J.* 2016, *118*(5), 5. DOI: 10.1108/BFJ-11-2015-0448.

[296] Albersmeier, F.; Schulze, H.; Jahn, G.; Spiller, A. The Reliability of Third-party Certification in the Food Chain: From Checklists to Risk-oriented Auditing. *Food Control.* 2009, *20*(10), 927–935. DOI: 10.1016/j.foodcont.2009.01.010.

[297] Abebe, G. F.; Bahn, R. A.; Chalak, A.; Yehya, A. A. K. Drivers for the Implementation of Market-based Food Safety Management Systems: Evidence from Lebanon. *Food Sci. Nutr.* 2020, *8*(2), 1082–1092. DOI: 10.1002/fsn3.1394.

[298] Karaman, A. D.; Cobanoglu, F.; Tunalioglu, R.; Ova, G. Barriers and Benefits of the Implementation of Food Safety Management Systems among the Turkish Dairy Industry: A Case Study. *Food Control.* 2012, *25*(2), 732–739. DOI: 10.1016/j.foodcont.2011.11.041.

[299] Vladimirov, Z.; Renko, S. Implementation of Food Safety Management System in Bulgaria. *Br. Food J.* 2011, *113* (1), 50–65. DOI: 10.1108/00070701111097330.

[300] Macheka, L.; Manditsera, F. A.; Ngadze, R. T.; Mubaiwa, J.; Nyanga, L. K. Barriers, Benefits and Motivation Factors for the Implementation of Food Safety Management System in the Food Sector in Harare Province, Zimbabwe. *Food Control.* 2013, *34*(1), 126–131. DOI: 10.1016/j.foodcont.2013.04.019.

[301] Mensah, L. D.; Julien, D. Implementation of Food Safety Management Systems in the UK. *Food Control.* 2011, *22* (8), 1216–1225. DOI: 10.1016/j.foodcont.2011.01.021.

[302] Bahn, R. A.; Abebe, G. K. Analysis of Food Retail Patterns in Urban, Peri-urban and Rural Settings: A Case Study from Lebanon. *Appl. Geogr.* 2017, *87*, 28–44. DOI: 10.1016/j.apgeog.2017.07.010.

[303] Henson, S.; Humphrey, J. Understanding the Complexities of Private Standards in Global Agri-food Chains as They Impact Developing Countries. *J. Develop. Stud.* 2010, *46*(9), 1628–1646. DOI: 10.1080/00220381003706494.

[304] Qijun, J.; Batt, P. J. Barriers and Benefits to the Adoption of a Third Party Certified Food Safety Management System in the Food Processing Sector in Shanghai, China. *Food Control.* 2016, *62*, 89–96. DOI: 10.1016/j.foodcont.2015.10.020.

[305] Kussaga, J. B.; Jacxsens, L.; Tiisekwa, B. P.; Luning, P. A. Food Safety Management Systems Performance in African Food Processing Companies: A Review of Deficiencies and Possible Improvement Strategies. *J. Sci. Food Agric.* 2014, *94*(11), 2154–2169. DOI: 10.1002/jsfa.6575.

[306] Park, S.; Hartley, J. L.; Wilson, D. Quality Management Practices and Their Relationship to Buyer's Supplier Ratings: A Study in the Korean Automotive Industry. *J. Oper. Manag.* 2001, *19*(6), 695–712. DOI: 10.1016/S0272-6963(01)00065-1.

[307] Ahire, S. L.; Dreyfus, P. The Impact of Design Management and Process Management on Quality: An Empirical Investigation. *J. Oper. Manag.* 2000, *18*(5), 549–575. DOI: 10.1016/S0272-6963(00)00029-2.

[308] Grandzol, J. R.; Gershon, M. Which TQM Practices Really Matter: An Empirical Investigation. *Qual. Manag. J.* 1997, *4*(4), 43–59. DOI: 10.1080/10686967.1998.11919147.

[309] Cohen, E.; Cukierman, G. E.; Schwartz, Z. Cutting Costs on Hazard Analysis Critical Control Points Systems in Food Catering: Sampling Frequency and the Rate of Misclassification. *J. Restaurant Food Serv. Marketing.* 2000, *4* (1), 19–29. DOI: 10.1300/J061v04n01_03.

[310] Juran, J. M.; Gryna, F. M. *Quality Planning and Analysis: From Product Development through Use*, 3rd Ed.; McGraw-Hill College: New York USA, 1993. pp. 672. ISBN 978-00070331839.

[311] Amar, K.; Zain, Z. M. Barriers to Implementing TQM in Indonesian Manufacturing Organizations. *TQM Mag.* 2002, *14*(6), 367–372. DOI: 10.1108/09544780210447474.

[312] Magd, H. A. E.;. ISO9001:2000 in the Egyptian Manufacturing Sector: Perceptions and Perspectives. *Int. J. Qual. Reliab. Manag.* 2008, *25*(2), 173–200. DOI: 10.1108/02656710810846934.

[313] Singh, R. K.; Garg, S. K.; Deshmukh, S. G. Strategy Development by Small Scale Industries in India. *Industrial Management & Data Systems.* 2010, *110*(7), 1073–1093. DOI: 10.1108/02635571011069112.

[314] Garwin, D. A.;. What Does Product Quality Really Mean? *Sloan Manag. Rev.* 1984, *26*(1), 25–43.

[315] Majid, M. A. M.; Abidin, I. H. Z.; Majid, H. A. M. A.; Chik, C. T. Issues of Halal Implementation in Malaysia. *J. Applied Environ. Biol. Sci.* 2015, *5*(6S), 50–56.

[316] Mohamed, Z.; Rezai, G.; Shamsudin, M. N.; Chiew, E. Halal Logo and Consumers' Confidence: What are Important Factors? *Econ. Technol. Manag. Rev.* 2008, 3, 37–45.

[317] Razali, M. R.; Yusoff, R. Z.; Mohd Roslan, M. W. A Framework of Halal Certification Practices in Hotel Industry. *Asian Soc. Sci.* 2013, *9*(11), 316–326.

[318] Holshue, M. L.; DeBolt, C.; Linquist, S.; Lofy, K. H.; Wiesman, J.; Bruce, H.; Spitters, C.; Ericson, K.; Wilkerson, S.; Tural, A.;, et al. First Case of 2019 Novel Coronavirus in the United States. *N. Engl. J. Med.* 2020, *382*(10), 929–936. DOI: 10.1056/NEJMoa2001191.

[319] Shahidi, F.;. Does COVID19 Affect Food Safety and Security? *J. Food Bioactives.* 2020, *9*. DOI: 10.31665/JFB.2020.9212.

04 czerwca 2023 r

(miejscowość i data)

…Charles Odilichukwu R. OKPALA…

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., & Korzeniowska, M. (2023). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. Food Reviews International, 39 (1), 1879-1952.*… mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

Okpala

04 June 2023……………

data i podpis

dr hab Małgorzata Korzeniowska, prof. uczelni

03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., & Korzeniowska, M. (2021). Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. Food Reviews International, 1-74* mój udział polegał na uczestnictwie w konceptualizacji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

foods

MDPI

Article

Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat

Charles Odilichukwu R. Okpala [1,2,*], Szymon Juchniewicz [1], Katarzyna Leicht [1], Małgorzata Korzeniowska [1] and Raquel P. F. Guiné [3]

1 Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wrocław University of Environmental and Life Sciences, 51-630 Wrocław, Poland
2 UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia, Athens, GA 30602, USA
3 CERNAS—Research Centre for Natural Resources, Environment and Society, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal
* Correspondence: charlesokpala@gmail.com

Abstract: The antioxidant, organoleptic, and physicochemical changes in different marinated oven-grilled chicken breast meat were investigated. Specifically, the chicken breast meat samples were procured from a local retailer in Wroclaw, Poland. The antioxidant aspects involved 2,2′-azinobis-(3-ethylbenzthiazolin-6-sulfonic acid) (ABTS), 1,1-diphenyl-2-pierylhydrazy (DPPH), and ferric-reducing antioxidant power (FRAP). The organoleptic aspects involved sensory and texture aspects. The physicochemical aspects involved the pH, thiobarbituric acid reactive substance (TBARS), cooking weight loss, L* a* b* color, and textural cutting force. Different marination variants comprised incremental 0.5, 1, and 1.5% concentrations of Baikal skullcap (BS), cranberry pomace (CP), and grape pomace (GP) that depicted antioxidants, and subsequently incorporated either African spice (AS) or an industrial marinade/pickle (IM). The oven grill facility was set at a temperature of 180 °C and a constant cooking time of 5 min. Results showed various antioxidant, organoleptic and physicochemical range values across the different marinated oven-grilled chicken breast meat samples, most of which appeared somewhat limited. Incorporating either AS or IM seemingly widens the ABTS and FRAP ranges, with much less for the DPPH. Moreover, with increasing CP, GP, and BS concentrations, fluctuations seemingly persist in pH, TBARS, cooking weight loss, L* a* b* color, and textural cutting force values even when either AS or IM was incorporated, despite resemblances in some organoleptic sensory and texture profiles. Overall, the oven-grilling approach promises to moderate the antioxidant, organoleptic, and physicochemical value ranges in the different marinated chicken breast meat samples in this study.

Keywords: oven-grill; herbs; spices; meat processing; product development

Citation: Okpala, C.O.R.; Juchniewicz, S.; Leicht, K.; Korzeniowska, M.; Guiné, R.P.F. Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. *Foods* **2022**, *11*, 3951. https://doi.org/10.3390/foods11243951

Academic Editor: Mi-Jung Choi

Received: 7 November 2022
Accepted: 2 December 2022
Published: 7 December 2022

1. Introduction

Within the European Union, particularly Poland, chicken meat thrives industrially through poultry production, which as of 2021 had amounted to an excess of 2.9 million metric tons [1,2]. Besides the poultry production system in Poland delivering a promising product quality [3], factors that influence the chick quality would include the assessment of day-olds, broiler breeder nutrition, flock age, egg storage, and its incubation/post-hatching period(s), as well as in ovo-feeding [4]. The passion for healthy living across the globe is among the keys that drive the steady increase in poultry meat production. Additionally, factors influencing the consumption of poultry meat products include visual and smell impressions, the color of the meat/carcass, the conditions of birds' housing/production systems, as well as the quality of the product/raw material contribute to the increasing poultry meat consumption [2]. Both the influencing factors of chick quality, as well as (poultry meat) consumption inevitably lead to the high demand for chicken/poultry meat by countless food services and associated processing industries [5]. Compared to red meat, chicken/poultry meat remains attractive given its high nutritive value, easier-to-handle cuts, and fewer associated religious restrictions [6,7]. Specifically, the proportion of unsaturated fatty acids, readily available protein, low energy content, as well as reasonable amounts of potassium, magnesium, zinc, and B group vitamins strengthens the nutritive value of broiler chicken meat [5]. Following meat and meat products and consumer preferences for poultry meat products [1–3], both the carcass characteristics [5,6], and (product) storage performance after various processing strategies [7–10], equally deserve full attention. Moreover, accelerated postmortem glycolysis is among the meat science tenets that bring about pale, soft, and exudative challenges in poultry meat [8]. The oxidation of polyunsaturated fatty acids (PUFA) in meat products either at cooking, digestion, or storage would facilitate a quality deterioration via advances of lipid oxidation end-products, and the formation of toxic compounds [9]. To avert this challenge, the refrigeration of freshly prepared broiler chicken meat products would reduce both microbial proliferation and lipid peroxidation, particularly during the storage periods. Moreover, seeking better processing and shelf-life extension strategies, for instance, the use of preservatives that help enhance the value of poultry products, are among the key interests of animal product stakeholders [8,10–12].

Marination remains among the existing traditional culinary techniques of seasoning. Typically, it involves the soaking of meat products in a slurry/solution that comprises a mix of different ingredients largely equipped with natural bioactive compounds, from vinegar, wine, soy sauce, salt, and herbs, to spices [11–13]. Marination processes vary across countries/regions, wherein consumers and other stakeholders apply them to various animal meat products largely directed for the enhancement of both moistness and sensory values, as well as for the provision of tenderness and other refinements to the texture [11–14]. Specifically, the bioactive compounds present in marinades exert antioxidant as well as antimicrobial potentials, which when applied to animal meat products, cumulatively enhance both the nutritional value and sensory attributes. Oftentimes, marinades would be applied alongside various seasonings with the aim to significantly influence the animal meat product's flavor development [12,13,15,16]. Indeed, herbs and spices provide beneficial/health-promoting phytochemicals, making their usage in food preservation increasingly important even in recent years [10,17]. More so, marinating ingredients can vary, with examples such as salt, peanut, ginger, black/regular pepper, cranberry pomace, Baikal skullcap (BS), etc. [9,18–22]. Salt enhances the flavor and tenderness, which provides antimicrobial and preservative activity for the meat [14,15]. Peanut (*Arachis hypogaea*) skin constitutes phenolics and other health-promoting compounds with its extract able to deliver total antioxidant activity believed to linearly corroborate the total phenolic concentration [21]. Ginger *(Zingiber officinale)* roots provide functional volatile oil derivatives, phenols, and flavonoids [23], with its extract able to deliver antioxidant properties [18]. Pepper serves important culinary purposes, and common examples include black, white, and green pepper types [9]. Black pepper (*Piper nigrum*), enriched with phenolic compounds, is often employed in meat preparation [9,22]. As a byproduct of cranberry processing with beneficial polyphenols, cranberry pomace is frequently discarded despite the extracts from its seeds, skins, and stems serving as a food ingredient [19]. Herbs such as Baikal skullcap (*Scutellaria baicalensis* L.), can provide antimicrobial effects to dairy products [20]. Moreover, there exists pickle making that involves vinegar/edible oil, salt, spices, and other condiments, which have been understood to offer a high nutritious value to poultry meat [24].

The pursuit of healthy living by consumers is among the crucial rationales that corroborate the increased demand for freshly prepared poultry meat, which associates strongly with their focus on nutritional improvement, not only in Poland but across Europe [2]. Whilst the combined effect of different marinades when applied to poultry meat helps to tenderize the muscle, extend the shelf time, and enhance the consumer appeal [9,11,12,18], the application of thermal treatment remains mandatory in actualizing an increased digestibility, decreased microbial proliferation, and enhanced flavor/texture [25]. In particular, thermal food processing has advanced even more in the recent decades, and examples can range from cook–chill, grilling, sous-vide, aseptic processing, and ohmic heating, to laser-based packaging [26]. Of interest to the authors of this current work is grilling, which depicts a cooking process/type that involves a significant amount of direct/radiant dry heat transferred by conduction [27,28]. When applied to animal meat products, this cooking process/type specifically confers a distinctive aroma and flavor that emanates from the Maillard reaction—a chemical process largely associated with temperatures higher than 155 °C (310 °F). Direct/radiant heat, such as those from a typical oven grill, capably delivers relatively high temperatures to reduce the cooking time of any given meat slice [27,28], as well as facilitate the loss of its fat and juiciness [29]. The charcoal type of grill appears relatively common, and is believed to prepare a chicken breast meat sample in 20 min [30]. Largely considered to be healthier than the charcoal type, oven-grilling remains a useful food process approach increasingly of research interest, particularly its application for animal/meat food products [31–33]; however, published information specific to the application of oven-grilling to different marinated chicken breast meat is scarce, to the best of our knowledge. Thus, further exploration specific to this research direction is warranted so as to enhance its consumer appeal and product development. Therefore, this current work investigated the antioxidant, organoleptic, and physicochemical changes in different marinated oven-grilled chicken breast meat. Specifically, the chicken breast meat samples were procured from a local retailer in Wroclaw, Poland. Additionally, the different marination variants involved cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS), which subsequently incorporated either African spice (AS) or industrial marinade/pickle (IM).

2. Materials and Methods

2.1. Schematic Overview of Experimental Program

The schematic overview of the experimental program, which depicts the major stages, from the procurement of the chicken breast meat samples, the preparation of marinade variants, through the oven-grilling activity, and subsequent analytical measurements, is shown in Figure 1. For emphasis, this work sought to understand the effects oven-grilling applied to chicken breast meat samples subject to different marination variant increments of BS, CP, and GP concentrations that subsequently incorporated either AS or IM, would deliver with respect to antioxidant, organoleptic, and physicochemical changes. Specifically, the antioxidant properties involved 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) (ABTS), 1,1-diphenyl-2-pierylhydrazy (DPPH), and ferric-reducing antioxidant power (FRAP). The organoleptic properties involved a sensory profile by way of flavor, appearance, tenderness and taste, and textural profile by way of hardness, chewiness, gumminess, graininess and greasiness. The physicochemical properties involved pH, thiobarbituric acid reactive substance (TBARS), cooking weight loss, L^* a^* b^* color, and textural cutting force. The chemicals and reagents employed in this study were of an analytical grade standard. All the conducted analytical measurements involving different marinated oven-grilled samples were independently performed consistent with the relevant guidelines set out by the Department of Functional Food Products Development, Wroclaw University of Environmental and Life Sciences, Poland.

2.2. Procurement, and Storage of Chicken Breast Meat Samples

The chicken breast meat samples (~20 kg) were procured from a local retail food distributor that serves the Wroclaw region, and immediately after, transported to the Department of Functional Food Products Development, Wroclaw University of Environmental and Life Sciences, Poland. Upon arrival, the chicken breast meat samples were rapidly stored in cold room refrigeration (~4 °C), and from there, made available for the marination and oven-grilling processes.

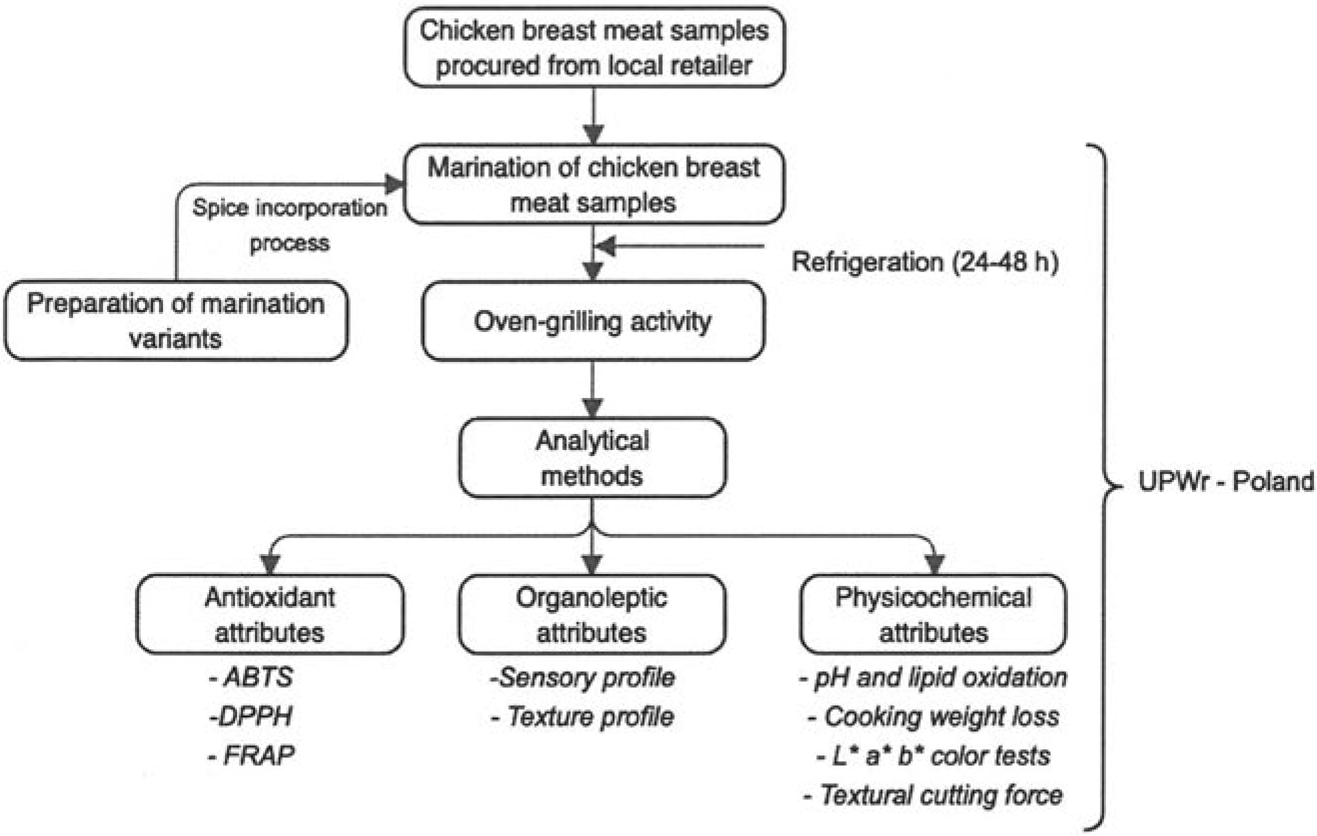

Figure 1. The schematic overview of the experimental program, which depicts the major stages, from the procurement of the chicken breast meat samples, preparation of marinade variants, through oven-grilling activity, and the subsequent analytical measurements. ABTS: 2,2′-Azinobis-(3-ethylbenzthiazoline-6-sulphonate); DPPH: 1,1-diphenyl-2-pierylhydrazy (radical scavenging activity); FRAP: ferric-reducing antioxidant power; UPWr: Uniwersytet Przyrodniczy we Wrocławiu (Wroclaw University of Environmental and Life Sciences, Poland).

2.3. Preparation of Marinades, and Marination Variants/Process

The preparation of the marinades involved salt (1.6 g), together with incremental 0.5, 1, and 1.5% constituent quantities of ground BS, CP, and GP been representative of additive antioxidants. To initiate a new product development perspective to this study, either African spice (AS) or industrial marinade/pickle (IM) (each constituting 4 g) were incorporated. Specifically, the African spice (Fresh and Tasty Kebab Powder) procured from Fresh and Tasty Farms Ltd. (Accra-North, Ghana) and prepared in adherence to the quality standards set by the Food and Drugs Authority (FDA) Ghana, comprised such ingredients as peanut and ginger, as well as black/regular pepper. This specific AS product was selected given its growing popularity and usage in barbecues in Wrocław (as well as other places in Poland). Further, the industrial marinade/pickle (Marinate do mięs) procured from Regis(R) Food Technology (Regis sp. z o.o., Kraków, Poland), whose preparation adhered to the quality standards of the International Organization for Standardization (ISO), British Retail Consortium (BRC), and International Food Standard (IFS), comprised such ingredients as thyme, oregano, rosemary, marjoram, and parsley. Additionally, this specific IM product was selected given its growing market and reputation not only in Poland, but also in other parts of the EU.

As mentioned earlier, the incremental constituent quantities of BS, CP and GP, which thereafter incorporated either AS or IM, resulted in the marination variants implemented as follows: (1) the control (antioxidant additive % = 0.0); (2) the control (antioxidant additive % = 0.5); (3) the control (antioxidant additive % = 1.0); (4) the control (antioxidant additive % = 1.5); (5) AS (antioxidant additive % = 0.0); (6) AS (antioxidant additive % = 0.5); (7) AS (antioxidant additive % = 1.0); (8) AS (antioxidant additive % = 1.5); (9) IM (antioxidant additive % = 0.0); (10) IM (antioxidant additive % = 0.5); (11) IM (antioxidant additive % = 1.0); and (12) IM (antioxidant additive % = 1.5). The immersion method as described by Sokołowicz et al. [12] with slight modifications was followed to implement the marination process of the chicken breast meat samples. This required the use of plastic containers approved for contact with food and a 1:2 ratio that applied to the weight of the meat (g) and marinade volume (mL). The chicken breast meat samples were dipped sufficiently in the marinade variants for a 24 h period at ~4 °C. When the marination immersion time had been completed, the samples were allowed to drain for 5 min, placed in folded foiled packages, and were then ready for the oven-grilling activity.

2.4. *Oven-Grilling Activity*

The oven-grill activity, consistent with the method modified from Salmon, Knize, and Felton [16], was applied to the various marinated chicken breast meat samples. The oven-grilling process employed a commercially available electric hot air convection type facility (CAMRY CR 6017, Serwis Centralny Camry, Warszawa, Poland) that operated with 2200 W power, and a set temperature of 180 °C. The chicken breast meat samples were placed evenly-spaced on a grill rack of the pre-heated oven, which had its heat setting set to move evenly from the bottom and from the top. The oven-grill facility remained closed during the cooking process, and would only be opened to either remove or place the samples. The internal temperatures of the chicken breast meat samples were routinely checked to keep them at roughly 75 °C. The cooking time was kept constant at 5 min, and this was applied to all the marinated samples in this study. After the oven-grill process had been completed, the chicken breast meat samples were allowed to briefly cool for 15 min, and then subsequently refrigerated (~4 °C) during which the samples were analyzed.

2.5. *Analytical Measurements*

2.5.1. Determination of Antioxidant Aspects

The 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) (ABTS) radical scavenging activity was determined following method described by Bai et al. [34] with a slight modification. Briefly, an already prepared $ABTS^+$ solution was diluted with ethanol. Subsequently, 990 µL of the $ABTS^+$ solution was added to 10 µL of a meat tissue supernatant, which was followed by incubation at ambient temperature (~25 °C) for 6 min. The blank comprised 990 µL of the $ABTS^+$ solution mixed with 10 µL of EtOH 70%. The absorbance was read against a blank at 734 nm using a UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, MA, USA), and the $ABTS^+$ radical scavenging activity was presented in mM Trolox.

The 1,1-diphenyl-2-pierylhydrazy (DPPH) radical scavenging activity was determined following method described by Zhang et al. [22] with a slight modification. The ethanolic DPPH radical solution (4 mg of DPPH in 100 mL of 95% ethyl alcohol) was freshly prepared. Briefly, aliquots (20 µL) from the meat tissue supernatant were vigorously mixed with 200 µL 0.3 mM of the ethanolic DPPH radical solution, by vortex for 1 min, and subsequently left to stand at ambient temperature (~25 °C) for 30 min in the dark. After incubation, the reduction of the DPPH was read at 517 nm using a UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, MA, USA) against a blank (1.5 mL of the DPPH solution and 1 mL of 95% ethanol). The DPPH radical scavenging activity was expressed in mM Trolox.

The ferric-reducing antioxidant power (FRAP) was determined as slightly modified from Lengkidworraphiphat et al. [35]. Ethanol extracts of chicken breast meat samples were prepared using 70% EtOH. The FRAP solution was comprised of 10 mM of 2,4,6-tripyridyl-s-triazine (TPTZ) and 20 mM of ferric chloride, added with 300 mM of a sodium acetate buffer (pH 3.6), at a ratio of 1:1:10 (*v:v:v*), which was incubated for 30 min at 37 °C. The blank was comprised of 3 mL of the FRAP reagent mixed with 1 mL of EtOH. The absorbance was read at 593 nm against the blank using a UV-Vis Spectrophotometer

(GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, Massachusetts-USA). The FRAP value of each sample was expressed as mM/dm^3.

2.5.2. Determination of Organoleptic Aspects

The organoleptic aspects of the various marinated oven-grilled chicken breast meat samples comprised sensorial analysis modified from Augustyńska-Prejsnar, Ormian, and Sokołowicz [36], and textural profiling modified from Sanchez Brambila, Bowker, and Zhuang [37]. The sensory panelists comprised ten (N = 10) staff and graduate students of the Department of Functional Food Products Development, Wrocław University of Environmental and Life Sciences (Wrocław-Poland). All panelists, already familiar with the evaluation criteria laid out specifically for this current study, were particularly required to discriminate between the levels of chicken breast meat's flavor, appearance, tenderness, taste, and off-flavor for the sensorial analysis, as well as the hardness, chewiness, gumminess, and graininess for the textural profiling. In addition to verbal consent taken prior to the organoleptic evaluation, and with the panelists' participation being voluntary, no names/genders were reported to ensure privacy. The organoleptic evaluation took place in a well-ventilated room of neutral color, proper lighting, and distraction-free. To perform the sensory and texture profile assessment, the evenly cut samples already cooled to $20 \pm 2°$ C were placed in coded white plastic plates in triplicates. Consistent with Çakmakçı et al. [38], each panelist used warm water to cleanse their taste palates between samples, to ensure the previous evaluation did not affect the (taste of the) new one. Each panelist simultaneously evaluated the coded samples using a five-point scale (1 point being the lowest score and 5 points being the highest) for the sensory aspects, and using a 0 to 15 intensity scale for the texture profile, as adapted from Civille and Thomas Carr [39].

2.5.3. Determination of Physicochemical Aspects

The pH measurement was determined as slightly modified from Barido and Lee [40], specifically conducted before and after the oven-grilling activity. This required a 5 g sample mixed with 45 mL of distilled water using a homogenizer (Model PH-91, SMT Company, Chiba, Japan) at 10,000 rpm, for 1 min. The portable pH meter (HI 99,163 Hanna Instrument Company, Vöhringen, Germany) was technically calibrated using buffer solutions (with an approximate pH of 4.0, 7.0 and 9.0) at ambient conditions. The variations in pH were elicited by a difference between those of the oven-grilled samples and the control.

The thiobarbituric acid reactive substance (TBARS) was determined as slightly modified from Luciano et al. [41], specifically conducted before and after the oven-grilling process. With the help of a stomacher, the chicken breast meat samples (1.0 g) were homogenized with 10 mL of 10% trichloroacetic acid (TCA) for 1 min to precipitate the proteins present in the meat. Next, there was a centrifugation at $4000\times g$ (MPW-351R refrigerated, MPW Med. Instruments, Warszawa, Poland), after which the emergent mix was subject to filtration (Whatman #1 filter paper), then 2 mL of the supernatant was transferred to 2 mL of 0.06 M thiobarbituric acid. The reaction mixture was kept in a water bath at 100 °C for 40 min, followed by cooling in an ice-water bath (~2 min). The calibration curve was prepared using 1,1,3,3-tetra-ethoxypropane in TCA, as a standard solution. The samples were finally analyzed, with the absorbance read at 532 nm using a UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, MA, USA). According to the standard curve equation, the TBARS values were reported as mg of malondialdehyde (MDA) per kg of meat sample.

The cooking weight loss was determined as slightly modified from Ali et al. [42]. Specifically, the samples were weighed prior to and after the oven-grilling. The cooking weight loss depicted the cooked sample (B) weight as a percentage of the precooked sample (A) weight, as shown by the Equation (1) below:

$$\text{Cooking loss (\%)} = [(A - B)/(A)] \times 100 \tag{1}$$

The color measurements were determined as slightly modified from Kopec et al. [43], specifically being conducted before and after oven-grilling by way of the CIE L* a* b* scale (L* = darkness; a* = redness/greenness; and b* = yellowness/blueness) using a Minolta CR-40 reflection colorimeter (Konica Minolta Sensing Europe B.V., NL-3439 MR, Nieuwegein, The Netherlands). Three individual measurements were taken of different areas on the chicken breast meat surface from each treatment group, and the results via the CIE L* a* b* colorimetric system were displayed in real-time.

The textural cutting force was determined as slightly modified from Augustyńska-Prejsnar, Ormian and Sokołowicz [44]. This required measuring the force that was necessary to cut a piece of a chicken breast meat sample. A Zwick/Roell testing machine (Zwick GmbH & Co. KG, Ulm, Germany), equipped with a Warner-Bratzler V-blade knife, was employed to measure the cutting force (Fmax) at a head speed of 100 mm/min and an initial force of 0.2 N. Three different chicken breast meat samples from each treatment group, with respective estimated cross-sectional diameters and lengths of 100 mm^2 and 50 mm, were subjected to textural cutting force measurements.

2.6. Statistical Analysis

The resultant data independently generated from the different samples using a minimum of two determinations, with a few exceptions, were given to a one-way analysis of variance (ANOVA). The results were represented as a mean ± standard deviation (SD). The probability level was statistically significant at $p < 0.05$ (95% confidence level). The Statistica 13.0 software (StatSoft GmbH, Hamburg Germany) was used to run the data.

3. Results and Discussion

3.1. Changes in Antioxidant Properties

Changes in the ABTS, DPPH, and FRAP values across the various marinated oven-grilled chicken breast meat samples compared to the controls can be seen in Figure 2. Overall, some statistical differences ($p < 0.05$) in the ABTS, DPPH, and FRAP occurred across the various marinated oven-grilled chicken breast meat samples either before or after incorporating the AS or IM, with minimum (ABTS = 1.82 ± 0.11 mM Trolox at IM + GP 1.5%; DPPH = 0.09 ± 0.00 mM Trolox at *Scutellaria* 0.5%; FRAP = 0.26 ± 0.07 mM/dm^3 at AS + CP 1%) and maximum(ABTS = 2.52 ± 0.21 mM Trolox at AS + *Scutellaria* 1%; DPPH = 0.15 ± 0.00 mM Trolox at IM + *Scutellaria* 1.5%; FRAP = 0.50 ± 0.19 mM/dm^3 at IM + *Scutellaria* 1.5%) values. Specifically, prior to incorporating either the AS or IM, both the ABTS and FRAP ranges appeared somewhat limited across the control samples of the CP, GP, and BS (ABTS = from 2.09 ± 0.02 to 2.36 ± 0.23 mM Trolox; FRAP range = from 0.30 ± 0.01 to 0.45 ± 0.02 mM/dm^3). However, applying either the AS or IM appeared to widen the ABTS and FRAP ranges of the various marinated oven-grilled chicken breast meat samples (specific to the AS, the ABTS range: from 2.22 ± 0.10 to 2.52 ± 0.21 mM Trolox; FRAP range = from 0.26 ± 0.07 to 0.41 ± 0.03 mM/dm^3; and specific to the IM, the ABTS range: from 1.82 ± 0.11 to 2.42 ± 0.06 mM Trolox; FRAP range = from 0.32 ± 0.04 to 0.50 ± 0.19 mM/dm^3), but not quite those of the DPPH. Moreover, the ABTS, DPPH, and FRAP values across the CP, GP and BS concentration increments seemingly likened those when either the AS or IM were incorporated. Probably, the individual/collective impact of the constituent ingredients that made up either the AS or IM contributed to the antioxidative efficacy.

Further, the ABTS, DPPH, and FRAP values would not necessarily align with either the CP, GP, or BS concentration increments despite their individual antioxidant potentials. For example, both Istrati et al. [11], and Shahidi and Hossain [17] considered herbs/spices with very promising antioxidant and antimicrobial properties, coupled with the acidic or alkaline nature of their solutions, poised to enhance the shelf quality of any given animal product. Additionally, measurements of ABTS, DPPH, and FRAP assays are increasingly frequent when evaluating the antioxidant activity of plant-oriented marinades/spices [10,22,35]. Notably, an ABTS assay would detect the generation of an ($ABTS^{+}$) radical, which is considered to be in a stable form prior to a reaction with antioxidants. Further, a DPPH assay would detect the capacity of antioxidants to decolorize a radical solution, which would suggest the lipophilic antioxidant level of a given food sample [45]. Contextualizing both ABTS and DPPH assays, Floegel et al. [45] considered both cranberry and grapes among the food items with a promising top total antioxidant capacity (TAC). Moreover, Sáyago-Ayerdi et al. [46] understood the GP composition to comprise concentrates of grape seeds, stems, and peel, which are enriched with phenolic compounds. Additionally, Kim et al. [47] considered the ethanol extracts of Baikal skullcap (BS) among the medicinal herbs with an antimicrobial potential, given the presence of amino acids, essential oils, flavones, and phenylethanoids, as well as sterols, whereas Lee et al. [48] considered the dried roots of BS to possess ample amounts of flavonoids.

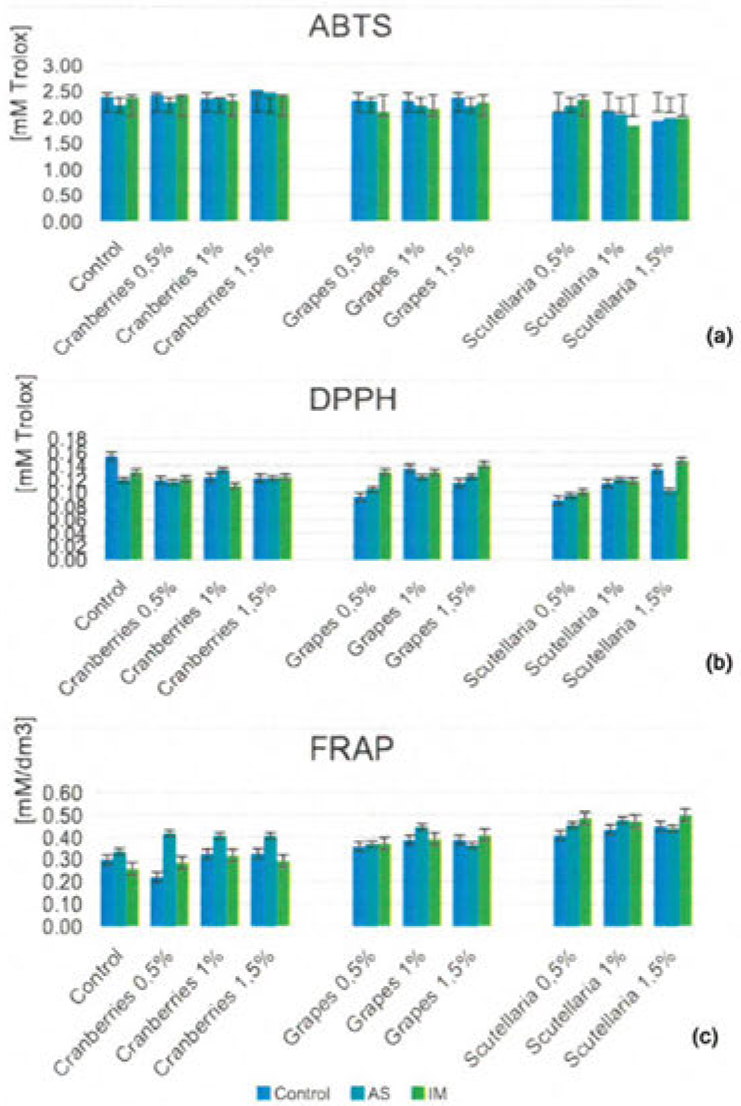

Figure 2. Changes in (a) ABTS, (b) DPPH, and (c) FRAP values across the various marinated oven-grilled chicken breast meat samples compared to a control. The marination variants involved cranberry pomace ("Cranberries" in Figure), grape pomace ("Grapes" in Figure) and Baikal skullcap ("Scutellaria" in Figure) that incorporated either African spice (AS) or industrial marinade/pickle (IM). Results are expressed as mean ± standard deviation (SD) at the probability level of $p < 0.05$. ABTS: 2,2′-Azinobis-(3-ethylbenzthiazoline-6-sulphonate); DPPH: 1,1-diphenyl-2-pierylhydrazy (radical scavenging activity); FRAP: ferric-reducing antioxidant power.

Considering that this current study had no storage period, understanding what brings about the interactive effects that emerge after applying antioxidant additive increments of either CP, GP, or BS concentrations alongside AS or IM for the various marinated oven-grilled chicken breast meat samples appear challenging. By studying whether the turmeric and black pepper spices were able to decrease the lipid peroxidation in meat patties, Zhang et al. [22] understood that the cooking temperatures might not necessarily contribute to the interactive effects (of combined turmeric and black pepper). Meanwhile, the incorporation of either CP, GP, or BS together with either AS or IM should constitute a herb mix with the capacity to increase the antioxidant activity of a given marinade medium, as well as decrease the lipid breakdown [22,25], and applying heat temperatures especially above 120 °C such as those with oven-grilling should capably decrease the antioxidant activity by breaking the primary compounds within the tissues (of a herb mix) [40]. By increasing the liberation of flavonoid and polyphenol bonds, such heat temperatures above 120 °C would further deactivate the endogenous oxidative enzymes, which could deter the availability of the antioxidative compound that would generate a more stable product [40].

3.2. Changes in Organoleptic Properties

Sensory evaluation is considered among the increasingly popular approaches employed in evaluating the freshness of marinated chicken meat products, given the fast, immediate, and simple information it provides regarding the product quality [49]. Herein, changes in the sensory profile by way of the flavor, appearance, tenderness, and taste, and the textural profile by way of the hardness, chewiness, gumminess, graininess, and greasiness of the various marinated oven-grilled chicken breast meat samples, are respectively shown in Tables 1 and 2. With the exception of the sensorial tenderness, as well as the textural chewiness, gumminess, and greasiness, there were resemblances ($p > 0.05$) in the organoleptic properties across the different marinated oven-grilled chicken breast meat samples, with promising ranges in the sensorial flavor (from 3.50 ± 1.28 to 4.31 ± 1.20), appearance (from 3.50 ± 0.60 to 4.25 ± 0.89), tenderness(from 3.19 ± 0.71 to 4.50 ± 0.76), taste (from 3.17 ± 0.95 to 4.31 ± 0.74), and flavor (from 4.00 ± 1.07 to 5.00 ± 1.41), and the textural hardness (from 2.88 ± 1.13 to 5.00 ± 1.51), chewiness (from 2.38 ± 1.30 to 4.25 ± 2.12), gumminess (from 2.00 ± 1.31 to 4.25 ± 1.49), graininess (from 2.25 ± 1.06 to 3.38 ± 1.25), and greasiness (from 1.56 ± 0.92 to 4.88 ± 2.70). Specifically, some fluctuating organoleptic values seemed apparent with increasing CP, GP, and BS concentrations. Incorporating either the AS or IM alone produced sensory scores of the flavor, appearance, tenderness, taste, and off-flavor that were likened with those of the CP, GP, and BS. Further, the textural hardness scores appeared seemingly higher for the GP, whereas this was true for the greasiness for the CP, and gumminess for the BS.

Table 1. Changes in sensory profile by way of flavor, appearance, tenderness, and taste across the various marinated oven-grilled chicken breast meat samples compared to the controls.

			Flavor	Apperance	Tenderness	Taste	Off-Flavor
Control	Control	0%	3.86 ± 0.96^{b}	3.83 ± 1.02^{b}	3.93 ± 0.82^{abc}	3.44 ± 0.62^{b}	4.63 ± 0.74^{b}
	Grape pomace	0.5%	3.75 ± 0.46^{b}	3.81 ± 0.65^{b}	3.56 ± 0.62^{abc}	3.31 ± 0.70^{b}	4.00 ± 1.07^{b}
		1%	3.81 ± 0.59^{b}	3.50 ± 0.60^{b}	3.94 ± 1.02^{abc}	3.94 ± 0.68^{b}	4.63 ± 0.52^{b}
		1.5%	3.94 ± 0.86^{b}	3.69 ± 0.80^{b}	4.00 ± 0.96^{abc}	3.88 ± 0.64^{b}	4.50 ± 0.76^{b}
	Cranberry pomace	0.5%	4.19 ± 1.04^{b}	3.94 ± 0.68^{b}	4.31 ± 0.93^{bc}	3.38 ± 0.92^{b}	4.38 ± 0.76^{b}
		1%	4.06 ± 0.64^{b}	3.88 ± 0.83^{b}	4.13 ± 0.68^{abc}	4.13 ± 0.52^{b}	4.56 ± 0.52^{b}
		1.5%	3.69 ± 1.24^{b}	3.88 ± 0.98^{b}	3.69 ± 0.73^{abc}	3.69 ± 0.99^{b}	4.19 ± 1.04^{b}

Table 1. *Cont.*

			Flavor	Apperance	Tenderness	Taste	Off-Flavor
	Scutellaria baicalensis	0.5%	3.61 ± 1.02^{b}	3.83 ± 1.13^{b}	3.67 ± 0.65^{abc}	3.17 ± 0.95^{b}	4.56 ± 0.62^{b}
		1%	3.81 ± 0.92^{b}	3.50 ± 0.83^{b}	3.19 ± 0.71^{ab}	3.19 ± 1.07^{b}	4.38 ± 0.46^{b}
		1.5%	3.81 ± 0.82^{b}	3.69 ± 0.93^{b}	4.25 ± 0.86^{bc}	3.63 ± 0.70^{b}	4.75± 0.50^{b}
African Spices	Control	0%	4.25 ± 0.71^{b}	3.88 ± 1.13^{b}	4.50 ± 0.76^{c}	4.25 ± 0.93^{b}	4.13 ± 1.36^{b}
	Grape pomace	0.5%	4.00 ± 0.89^{b}	3.94 ± 0.78^{b}	4.06 ± 0.50^{abc}	4.31 ± 0.46^{b}	4.25 ± 1.04^{b}
		1%	3.94 ± 0.78^{b}	3.88 ± 0.83^{b}	4.19 ± 0.75^{bc}	3.88 ± 0.64^{b}	4.25 ± 1.16^{b}
		1.5%	3.75 ± 1.25^{b}	3.75 ± 1.07^{b}	3.56 ± 1.18^{abc}	3.88 ± 0.99^{b}	4.50 ± 0.76^{b}
	Cranberry pomace	0.5%	4.19 ± 0.73^{b}	4.25 ± 0.76^{b}	4.00 ± 0.64^{abc}	4.00 ± 0.83^{b}	4.25 ± 1.16^{b}
		1%	4.19 ± 0.65^{b}	4.00 ± 0.92^{b}	3.81± 0.75^{abc}	3.88 ± 0.86^{b}	4.25 ± 0.93^{b}
		1.5%	3.94 ± 1.08^{b}	3.94 ± 1.07^{b}	3.88 ± 0.52^{abc}	3.94 ± 0.95^{b}	4.38 ± 1.07^{b}
	Scutellaria baicalensis	0.5%	3.93 ± 1.35^{b}	3.86 ± 1.22^{b}	3.93 ± 0.46^{abc}	4.00± 1.44^{b}	5.00 ± 1.41^{b}
		1%	3.81 ± 0.65^{b}	4.13 ± 1.31^{b}	3.75 ± 0.92^{abc}	3.81 ± 1.00^{b}	4.75 ± 1.06^{b}
		1.5%	3.94 ± 0.92^{b}	4.00 ± 1.03^{b}	4.06 ± 0.65^{abc}	4.31 ± 0.74^{b}	5.00 ± 0.46^{b}
Industrial	Control	0%	4.06 ± 1.27^{b}	4.25 ± 0.71^{b}	4.13 ± 0.83^{abc}	4.00 ± 1.07^{b}	4.13 ± 1.13^{b}
	Grape pomace	0.5%	4.13 ± 0.99^{b}	3.63 ± 0.74^{b}	3.69 ± 0.70^{abc}	4.06 ± 0.68^{b}	4.25 ± 1.16^{b}
		1%	3.69 ± 1.19^{b}	3.69 ± 0.96^{b}	3.94 ± 0.82^{abc}	3.94 ± 0.68^{b}	4.13 ± 1.13^{b}
		1.5%	3.50 ± 1.28^{b}	3.88 ± 0.69^{b}	4.06 ± 0.94^{abc}	3.75 ± 1.04^{b}	4.13 ± 1.46^{b}
	Cranberry pomace	0.5%	3.81 ± 0.65^{b}	4.25 ± 0.83^{b}	4.13 ± 0.92^{abc}	3.94 ± 0.50^{b}	4.13 ± 0.93^{b}
		1%	3.94 ± 1.03^{b}	4.06 ± 0.76^{b}	4.25 ± 1.02^{bc}	4.00 ± 1.07^{b}	4.44 ± 1.16^{b}
		1.5%	4.31 ± 1.20^{b}	4.25 ± 0.89^{b}	4.13 ± 1.28^{abc}	4.25 ± 1.04^{b}	4.50 ± 0.73^{b}
	Scutellaria baicalensis	0.5%	4.19 ± 1.13^{b}	3.94 ± 0.83^{b}	3.88 ± 0.69^{abc}	4.00 ± 0.92^{b}	4.25 ± 0.52^{b}
		1%	4.13 ± 1.16^{b}	3.88 ± 1.41^{b}	3.88 ± 0.98^{abc}	4.19 ± 1.06^{b}	4.63 ± 1.41^{b}
		1.5%	4.25 ± 1.22^{b}	4.00 ± 0.74^{b}	3.56 ± 0.72^{abc}	3.63 ± 0.88^{b}	4.38 ± 0.89^{b}

Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) do not differ significantly ($p > 0.05$).

Table 2. Changes in textural profile by way of hardness, chewiness, gumminess, graininess, and greasiness across the various marinated oven-grilled chicken breast meat samples compared to the controls.

			Hardness	Chewiness	Gumminess	Graininess	Greasiness
Control	Control	0%	4.25 ± 1.39^{a}	3.63 ± 1.19^{ab}	2.88 ± 1.13^{ab}	2.50 ± 0.92^{ab}	2.25 ± 1.04^{abcde}
	Grape pomace	0.5%	4.25 ± 1.75^{a}	3.38 ± 1.30^{ab}	2.88 ± 0.99^{ab}	3.38 ± 1.13^{ab}	2.25 ± 1.16^{abcde}
		1%	3.13 ± 1.55^{a}	2.63 ± 1.06^{a}	2.13 ± 1.25^{ab}	2.63 ± 1.41^{ab}	2.00 ± 1.07^{abcd}
		1.5%	4.13 ± 1.64^{a}	3.25 ± 0.89^{ab}	2.88 ± 1.25^{ab}	3.25 ± 1.46^{ab}	2.63 ± 1.85^{abcde}
	Cranberry pomace	0.5%	3.13 ± 1.55^{a}	2.88 ± 1.36^{a}	3.00 ± 1.20^{ab}	2.88 ± 1.49^{ab}	4.63 ± 2.33^{de}
		1%	3.75 ± 1.75^{a}	3.75 ± 1.04^{ab}	3.50 ± 1.41^{ab}	2.88 ± 2.07^{ab}	3.75 ± 2.49^{bcde}
		1.5%	4.50 ± 2.45^{a}	3.50 ± 1.07^{ab}	3.25 ± 1.04^{ab}	4.25 ± 1.36^{b}	3.50 ± 1.85^{abcde}
	Scutellaria baicalensis	0.5%	3.56 ± 1.58^{a}	3.78 ± 1.60^{ab}	3.78 ± 2.00^{ab}	2.57 ± 1.41^{ab}	1.56 ± 0.92^{ab}
		1%	4.25 ± 1.91^{a}	3.38 ± 1.69^{ab}	4.00 ± 2.78^{ab}	2.25 ± 1.06^{ab}	2.50 ± 1.77^{abcde}
		1.5%	3.38 ± 1.69^{a}	3.75 ± 1.67^{ab}	3.69 ± 1.71^{ab}	3.00 ± 1.68^{ab}	3.63 ± 3.02^{abcde}

Table 2. *Cont.*

			Hardness	Chewiness	Gumminess	Graininess	Greasiness
African Spices	Control	0%	2.88 ± 1.89[a]	2.38 ± 1.30[a]	2.00 ± 1.31[a]	2.63 ± 1.31[ab]	2.50 ± 1.41[abcde]
	Grape pomace	0.5%	4.25 ± 1.04[a]	2.88 ± 1.13[a]	2.56 ± 1.24[ab]	3.13 ± 1.60[ab]	2.25 ± 1.10[abcde]
		1%	3.00 ± 1.77[ab]	2.75 ± 1.67[a]	3.06 ± 1.43[ab]	2.50 ± 1.41[ab]	1.88 ± 0.83[abc]
		1.5%	5.00 ± 1.51[a]	3.88 ± 1.96[ab]	4.00 ± 2.67[ab]	2.88 ± 1.83[ab]	2.75 ± 1.91[abcde]
	Cranberry pomace	0.5%	3.25 ± 1.28[a]	3.50 ± 1.60[ab]	3.25 ± 1.83[ab]	2.75 ± 1.46[ab]	3.75 ± 2.49[bcde]
		1%	4.13 ± 1.96[a]	3.75 ± 1.49[ab]	4.00 ± 1.51[ab]	3.38 ± 1.25[ab]	3.38 ± 1.77[abcde]
		1.5%	3.63 ± 2.45[a]	4.13 ± 1.46[ab]	4.25 ± 1.49[b]	2.88 ± 1.49[ab]	4.00 ± 2.20[bcde]
	Scutellaria baicalensis	0.5%	4.14 ± 1.02[a]	4.21 ± 1.13[ab]	3.29 ± 0.65[ab]	2.56 ± 0.95[ab]	3.57 ± 0.53[abcde]
		1%	4.13 ± 0.92[a]	3.44 ± 0.83[ab]	2.88 ± 0.71[ab]	2.38 ± 1.07[ab]	2.38 ± 0.46[abcde]
		1.5%	4.00 ± 2.62[a]	3.88 ± 2.17[ab]	3.06 ± 1.37[ab]	2.44 ± 1.85[ab]	3.00 ± 2.14[abcde]
Industrial pickle	Control	0%	3.50 ± 1.31[a]	2.88 ± 0.83[a]	3.00 ± 1.20[ab]	2.63 ± 1.06[ab]	3.50 ± 1.07[abcd]
	Grape pomace	0.5%	3.75 ± 1.75[a]	3.75 ± 1.75[ab]	3.25 ± 1.28[ab]	2.88 ± 1.36[ab]	2.00 ± 1.07[abcd]
		1%	2.88 ± 1.13[a]	2.69 ± 0.96[a]	2.88 ± 1.13[ab]	2.75 ± 1.04[ab]	2.38 ± 1.30[abcde]
		1.5%	3.00 ± 1.69[a]	3.38 ± 1.85[ab]	2.50 ± 0.93[ab]	2.75 ± 1.67[ab]	2.38 ± 1.41[abcde]
	Cranberry pomace	0.5%	3.88 ± 1.36[a]	3.38 ± 1.69[ab]	3.38 ± 1.19[ab]	3.00 ± 1.31[ab]	4.25 ± 2.55[bcde]
		1%	2.88 ± 1.55[a]	2.63 ± 1.60[a]	2.81 ± 1.41[ab]	2.75 ± 1.49[ab]	4.88 ± 2.70[e]
		1.5%	3.25 ± 1.58[a]	3.25 ± 1.83[ab]	3.13 ± 1.55[ab]	2.50 ± 1.51[ab]	4.75 ± 2.49[e]
	Scutellaria baicalensis	0.5%	4.50 ± 2.00[a]	4.00 ± 1.41[ab]	3.88 ± 2.23[ab]	3.00 ± 2.00[ab]	3.00 ± 2.14[abcde]
		1%	3.88 ± 1.46[a]	3.63 ± 1.77[ab]	3.50 ± 1.41[ab]	2.50 ± 1.51[ab]	3.25 ± 2.19[abcde]
		1.5%	4.50 ± 2.20[a]	4.25 ± 2.12[ab]	3.63 ± 2.26[ab]	3.00 ± 2.33[ab]	3.63 ± 2.72[abcde]

Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) do not differ significantly ($p > 0.05$).

Generally, consumer perceptions and responses to organoleptic textures would vary, for instance, in the attributes associated with tenderness [50]. Whereas the human senses altogether would help in ascertaining the overall acceptability by detecting such sensory properties as the appearance, flavor, taste, and texture, a descriptive sensory analysis should provide trained panels the capacity to discriminate different/diverse sensory aspects [51] of any given tested animal food products. In the current study, for example, a higher textural hardness score could occur when the AS was incorporated, particularly for the BS of different marinated oven-grilled chicken breast meat samples. Conversely, as the IM was incorporated, higher textural chewiness scores could occur either for the GP, or greasiness scores for the CP, or hardness scores for the BS. Given the somewhat limited range values, establishing the specific organoleptic sensory and texture profile trends across the various marinated oven-grilled chicken breast meat samples of this study appear challenging (Tables 1 and 2). This might corroborate the somewhat limited ranges of both the antioxidant and physicochemical outcomes observed at other sections of this work, especially where those of increasing CP, GP, and BS concentrations likened with those incorporating either AS or IM (Refer to Figures 2–6 and Figure 7 in Ref, and Table 3). The numerical texture data obtained from instrumental measurements corroborated the sensory results. Additionally, instrumental texture would corroborate the sensory tenderness acceptability, as evidenced in chicken breast meat reported elsewhere [52], and such a sensory-texture connection should be obtainable given the highly cross-linked nature of collagen that would be elevated at the post-slaughter stage, which eventually toughens a poultry chicken meat product [53]. Largely, such factors such as the connective tissue and cross-linking, intramuscular fat (IMF), myofibrillar integrity, and protein denaturation during cooking, as well as the sarcomere length would influence meat tenderness [50].

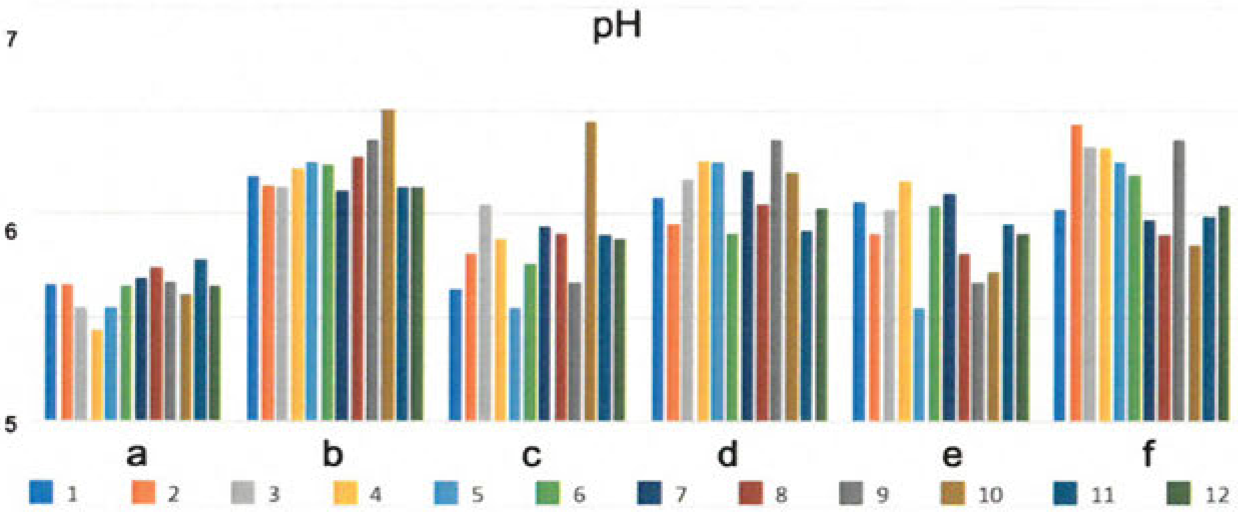

Figure 3. Changes in pH across the various marinated chicken breast meat samples before and after oven-grilling. The different letters (shown along the *x*-axis) represent as follows: (a) CP before oven-grill; (b) CP after oven-grill; (c) GP before oven-grill; (d) GP after oven-grill; (e) BS before oven-grill; (f) BS after oven-grill. The numbers representing the different color shades are as follows: (1) control (antioxidant additive % = 0.0); (2) control (antioxidant additive % = 0.5); (3) control (antioxidant additive % = 1.0); (4) control (antioxidant additive % = 1.5); (5) AS (antioxidant additive % = 0.0); (6) AS (antioxidant additive % = 0.5); (7) AS (antioxidant additive % = 1.0); (8) AS (antioxidant additive % = 1.5); (9) IM (antioxidant additive % = 0.0); (10) IM (antioxidant additive % = 0.5); (11) IM (antioxidant additive % = 1.0); (12) IM (antioxidant additive % = 1.5). African spice: AS; industrial marinade/pickle: IM; CP: cranberry pomace; GP: grape pomace; BS: Baikal skullcap.

3.3. Changes in Physicochemical Properties

Changes in the pH, TBARS, cooking weight loss, L* a* b* color, and textural cutting force across the various marinated oven-grilled chicken breast meat samples compared to the control, respectively, are shown in Figures 3–6 and Tables 3 and 4. Increasing either the CP, GP, or BS concentrations produced varying pH, TBARS, cooking weight loss, L* a* b* color, and textural cutting force values, which in many instances could not demonstrate a distinct trend. For instance, without incorporating either AS or IM, the pH showed somewhat limited ranges, such as the CP pre-oven grill (from 5.44 to 5.78), CP post-oven grill (from 6.11 to 6.51), GP pre-oven grill (from 5.55 to 6.45), GP post-oven grill (from 5.91 to 6.36), BS pre-oven grill (from 5.55 to 6.16), and BS post-oven grill (from 5.85 to 6.44) (Figure 3). A greater variation of pH by difference seemed so at the concentration increments of the CP, slightly less at GP, followed by BS (Figure 4). In studying the antimicrobial/antioxidant activities of spice extracts on raw chicken meat quality, Zhang, Wu and Gun [10] reported an initial pH of 5.65 ± 0.05 at the beginning of the storage period. Associated with pH increases could be the accumulation of ammonia, and the utilization of amino acids by bacteria being released during protein degradation. Moreover, antimicrobial ingredients in natural spices could provide some inhibitory effects that could be associated with pH decreases [10]. Additionally, herbs/plants that contain a high antioxidant capacity should capably prevent pH increases. Consequently, the pH range values of the various marinated oven-grilled chicken breast meat samples might corroborate the widely-accepted post-rigor value range of 5.90–6.10 [40].

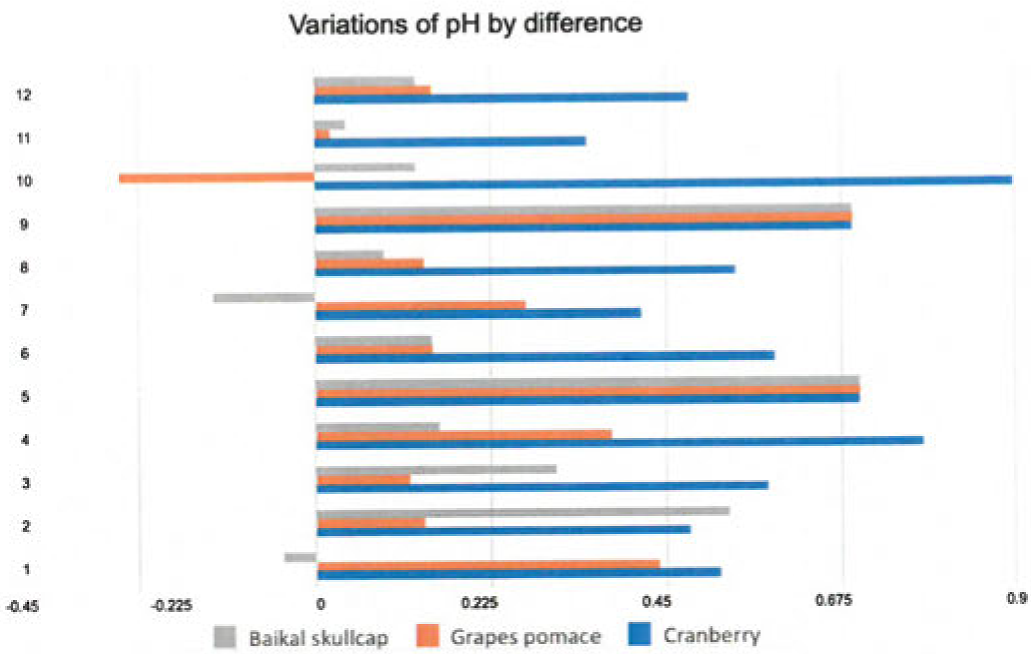

Figure 4. Variations of pH by difference across the various marinated oven-grilled chicken breast meat samples. The numbers (shown along the *y*-axis) represent as follows: (1) control (antioxidant additive % = 0.0); (2) control (antioxidant additive % = 0.5); (3) control (antioxidant additive % = 1.0); (4) control (antioxidant additive % = 1.5); (5) AS (antioxidant additive % = 0.0); (6) AS (antioxidant additive % = 0.5); (7) AS (antioxidant additive % = 1.0); (8) AS (antioxidant additive % = 1.5); (9) IM (antioxidant additive % = 0.0); (10) IM (antioxidant additive % = 0.5); (11) IM (antioxidant additive % = 1.0); (12) IM (antioxidant additive % = 1.5). African spice: AS; and industrial marinade/pickle: IM.

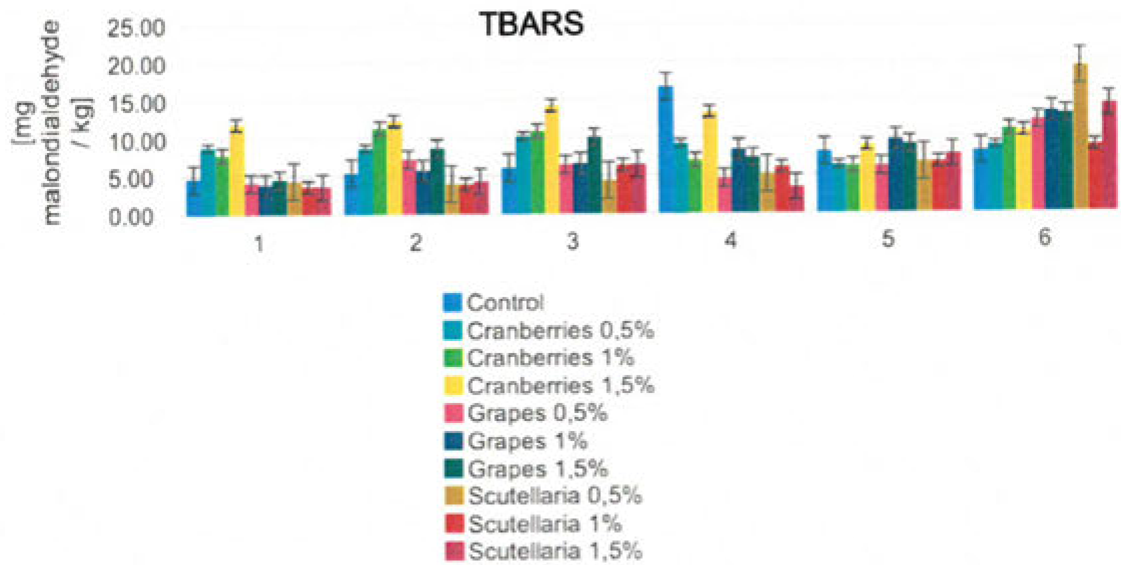

Figure 5. Changes in thiobarbituric acid reactive substance (TBARS) across the various marinated oven-grilled chicken breast meat samples. Results are expressed as mean ± standard deviation (SD) at the probability level of $p < 0.05$. The numbers (shown along the *x*-axis) represent as follows: (1) control before oven-grill; (2) AS before oven-grill; (3) IM before oven-grill; (4) control after oven-grill; (5) AS after oven-grill; (6) IM after oven-grill; African spice: AS; and industrial marinade/pickle: IM.

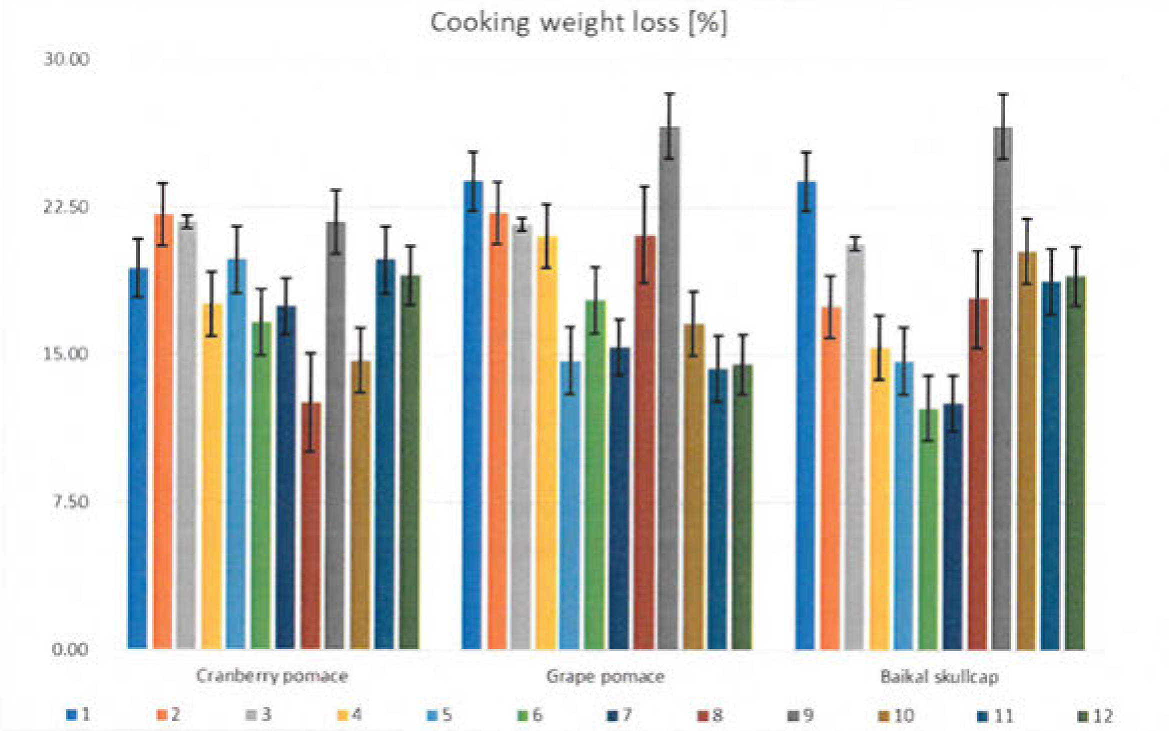

Figure 6. Changes in cooking weight loss (%) across the various marinated oven-grilled chicken breast meat samples compared to the control. Results are expressed as mean ± standard deviation (SD) at the probability level of $p < 0.05$. The numbers representing different color shades are as follows: (1) control (antioxidant additive % = 0.0); (2) control (antioxidant additive % = 0.5); (3) control (antioxidant additive % = 1.0); (4) control (antioxidant additive % = 1.5); (5) AS (antioxidant additive % = 0.0); (6) AS (antioxidant additive % = 0.5); (7) AS (antioxidant additive % = 1.0); (8) AS (antioxidant additive % = 1.5); (9) IM (antioxidant additive % = 0.0); (10) IM (antioxidant additive % = 0.5); (11) IM (antioxidant additive % = 1.0); (12) IM (antioxidant additive % = 1.5). African spice: AS; and industrial marinade/pickle: IM.

Table 3. (a–c) Changes in L* a* b* color across the various marinated oven-grilled chicken breast meat samples incorporating (a) cranberry pomace (CP), (b) grape pomace (GP), and (c) Baikal skullcap (BS) compared to the control.

(a) cranberry Pomace (CP) before and after Oven-Grill						
	CP before Oven-Grill			CP after Oven-Grill		
Samples	L*	a*	b*	L*	a*	b*
1	54.2 ± 1.3^{a}	0.5 ± 0.2^{cd}	7.41 ± 1.1^{bc}	76.4 ± 1.8^{a}	-1.8 ± 0.1^{c}	18.6 ± 2.1^{de}
2	48.8 ± 3.2^{bcd}	5.8 ± 1.3^{a}	3.2 ± 0.5^{cd}	67.7 ± 2.5^{bc}	1.6 ± 1.2^{b}	12.0 ± 2.5^{g}
3	51.5 ± 2.6^{abc}	2.1 ± 1.7^{bcd}	5.4 ± 0.7^{cd}	73.3 ± 4.5^{ab}	-0.9 ± 3.4^{bc}	16.7 ± 1.0^{ef}
4	48.4 ± 1.4^{bcd}	5.6 ± 1.1^{a}	2.6 ± 1.5^{d}	70.5 ± 0.3^{b}	0.2 ± 0.4^{abc}	14.0 ± 1.1^{fg}
5	51.2 ± 5.3^{abcd}	2.5 ± 0.6^{bc}	12.9 ± 1.6^{a}	68.2 ± 2.8^{bc}	1.2 ± 1.5^{ab}	20.7 ± 0.7^{bcd}
6	46.1 ± 4.3^{d}	3.6 ± 1.0^{b}	11.9 ± 0.4^{ab}	69.6 ± 4.2^{bc}	0.2 ± 0.8^{abc}	21.5 ± 1.0^{bcd}
7	52.5 ± 2.2^{ab}	3.6 ± 2.1^{b}	14.3 ± 5.9^{a}	68.5 ± 3.9^{bc}	0.6 ± 0.8^{abc}	20.2 ± 0.7^{cd}
8	47.3 ± 0.5^{bcd}	3.2 ± 0.8^{b}	10.8 ± 2.8^{ab}	64.3 ± 3.3^{cd}	3.0 ± 1.3^{a}	21.7 ± 2.3^{bcd}
9	52.5 ± 2.0^{ab}	0.3 ± 0.9^{d}	14.8 ± 1.5^{a}	71.3 ± 1.9^{cb}	0.1 ± 1.4^{abc}	28.2 ± 3.9^{a}

Table 3. *Cont.*

(a) cranberry Pomace (CP) before and after Oven-Grill						
	CP before Oven-Grill			CP after Oven-Grill		
Samples	**L***	**a***	**b***	**L***	**a***	**b***
10	47.1 ± 1.2^{cd}	2.3 ± 1.1^{cd}	10.3 ± 3.8^{ab}	68.0 ± 5.5^{bc}	0.8 ± 1.4^{abc}	22.6 ± 1.5^{bc}
11	49.7 ± 1.9^{abcd}	3.4 ± 0.8^{b}	14.6 ± 2.4^{a}	60.2 ± 2.4^{d}	2.8 ± 1.1^{a}	24.0 ± 2.4^{b}
12	50.8 ± 2.1^{abcd}	2.5 ± 0.8^{bc}	12.6 ± 1.3^{a}	69.8 ± 0.3^{bc}	0.4 ± 0.7^{abc}	21.7 ± 1.1^{bcd}
(b) grape pomace (GP) before and after oven-grill.						
	GP before oven-grill			GP after oven-grill		
Samples	L*	a*	b*	L*	a*	b*
1	52.1 ± 2.9^{abc}	1.6 ± 0.9^{cde}	4.9 ± 1.1^{de}	83.3 ± 1.1^{a}	0.8 ± 0.9^{f}	15.7 ± 1.0^{ef}
2	50.7 ± 1.8^{abcd}	1.3 ± 0.8^{de}	5.4 ± 3.9^{de}	75.6 ± 3.0^{bc}	1.5 ± 0.7^{ef}	14.8 ± 1.4^{f}
3	53.8 ± 3.6^{a}	1.1 ± 0.5^{e}	2.4 ± 1.3^{e}	78.0 ± 3.4^{ab}	1.7 ± 1.0^{def}	12.4 ± 3.8^{f}
4	49.4 ± 3.4^{abcd}	2.0 ± 0.1^{abcde}	6.1 ± 2.9^{de}	69.8 ± 6.3^{cde}	3.3 ± 0.7^{abcd}	13.2 ± 1.9^{f}
5	49.2 ± 0.9^{abcd}	1.9 ± 0.5^{bcde}	13.4 ± 1.6^{b}	76.5 ± 3.5^{abc}	2.4 ± 0.4^{bcdef}	20.7 ± 2.1^{cd}
6	43.7 ± 2.9^{d}	3.5 ± 1.2^{a}	13.3 ± 2.4^{b}	73.0 ± 2.3^{bcd}	2.2 ± 0.1^{cdef}	19.9 ± 1.8^{d}
7	46.1 ± 0.6^{bcd}	3.5 ± 0.2^{ab}	18.5 ± 0.8^{a}	69.1 ± 5.4^{cde}	3.8 ± 1.4^{abc}	19.5 ± 2.3^{de}
8	53.4 ± 6.5^{ab}	3.1 ± 0.6^{abc}	9.5 ± 2.2^{bcd}	65.7 ± 2.7^{de}	4.5 ± 1.2^{a}	19.6 ± 1.8^{de}
9	51.9 ± 4.4^{abc}	2.4 ± 1.0^{abcde}	12.6 ± 0.5^{bc}	66.8 ± 5.2^{de}	3.8 ± 1.0^{abc}	29.1 ± 1.4^{a}
10	46.5 ± 1.7^{abcd}	2.8 ± 1.4^{abcd}	13.4 ± 5.5^{b}	66.0 ± 1.6^{de}	4.1 ± 0.4^{ab}	25.7 ± 2.6^{ab}
11	52.1 ± 2.4^{abc}	1.4 ± 0.6^{de}	13.5 ± 3.3^{b}	63.8 ± 4.2^{e}	4.0 ± 0.1^{ab}	26.0 ± 2.4^{ab}
12	45.0 ± 2.6^{cd}	2.3 ± 0.6^{abcde}	8.1 ± 0.4^{cd}	71.2 ± 5.0^{bcde}	3.2 ± 1.4^{abcde}	24.0 ± 2.3^{bc}
(c) Baikal skullcap (BS) before and after oven-grill						
	BS before oven-grill			BS after oven-grill		
Samples	L*	a*	b*	L*	a*	b*
1	45.0 ± 0.1^{bcd}	−0.3 ± 0.4^{bcd}	4.3 ± 2.5^{e}	77.0 ± 1.7^{a}	−1.8 ± 0.4^{cd}	18.8 ± 1.0^{c}
2	48.7 ± 3.5^{abc}	−0.9 ± 0.2^{cde}	8.7 ± 0.6^{cd}	73.6 ± 5.0^{abc}	−2.6 ± 0.1^{d}	17.3 ± 5.2^{c}
3	44.8 ± 4.7^{bcd}	−0.6 ± 0.3^{cde}	7.0 ± 0.8^{de}	74.2 ± 1.2^{abc}	−2.5 ± 0.8^{d}	15.8 ± 1.3^{c}
4	46.2 ± 1.0^{bcd}	−1.6 ± 1.0^{e}	11.5 ± 3.8^{bcd}	71.4 ± 2.5^{abcd}	−2.2 ± 0.4^{d}	18.0 ± 1.5^{c}
5	49.2 ± 0.9^{ab}	1.9 ± 0.5^{a}	13.4 ± 1.6^{ab}	76.5 ± 3.5^{ab}	2.4 ± 0.4^{ab}	20.7 ± 2.1^{bc}
6	41.7 ± 2.4^{d}	0.7 ± 1.1^{b}	15.9 ± 3.3^{ab}	63.0 ± 9.1^{de}	1.6 ± 2.6^{ab}	24.8 ± 4.8^{ab}
7	44.0 ± 2.9^{cd}	0.3 ± 0.3^{bc}	14.6 ± 1.8^{ab}	61.5 ± 2.1^{e}	1.5 ± 1.0^{b}	25.3 ± 0.6^{ab}
8	42.6 ± 1.5^{d}	0.3 ± 0.1^{bc}	17.2 ± 2.7^{a}	61.4 ± 9.2^{e}	0.3 ± 2.6^{bc}	25.4 ± 2.4^{ab}
9	51.9 ± 4.4^{ab}	2.4 ± 1.0^{a}	12.6 ± 0.5^{abc}	66.8 ± 5.2^{bcde}	3.8 ± 1.0^{a}	29.1 ± 1.4^{a}
10	44.3 ± 3.4^{bcd}	−0.2 ± 0.1^{bcd}	15.0 ± 3.8^{ab}	68.3 ± 6.7^{abcde}	−1.1 ± 0.3^{cd}	26.9 ± 1.6^{a}
11	48.9 ± 0.8^{abc}	−1.7 ± 0.6^{e}	14.4 ± 2.3^{ab}	64.8 ± 2.2^{cde}	−1.4 ± 1.0^{cd}	25.5 ± 2.3^{ab}
12	45.6 ± 0.5^{bcd}	−1.1 ± 0.5^{de}	14.7 ± 2.0^{ab}	63.5 ± 4.7^{de}	0.4 ± 0.1^{bc}	28.6 ± 3.1^{a}

Key: Results are expressed as mean ± standard deviation (SD) at the probability level of $p < 0.05$. The numbers representing the samples are as follows: (1) control (antioxidant additive % = 0.0); (2) control (antioxidant additive % = 0.5); (3) control (antioxidant additive % = 1.0); (4) control (antioxidant additive % = 1.5); (5) AS (antioxidant additive % = 0.0); (6) AS (antioxidant additive % = 0.5); (7) AS (antioxidant additive % = 1.0); (8) AS (antioxidant additive % = 1.5); (9) IM (antioxidant additive % = 0.0); (10) IM (antioxidant additive % = 0.5); (11) IM (antioxidant additive % = 1.0); (12) IM (antioxidant additive % = 1.5). African spice: AS; and industrial marinade/pickle: IM.

Table 4. Changes in textural cutting force across the various marinated oven-grilled chicken breast meat samples compared to control.

Antioxidant Additive	Marinade Type	Percentage (%) of Antioxidant Additive	Chicken Cutting Force [N]
Cranberry pomace	Control	0.0	17.3 ± 1.0^{cdefghi}
		0.5	13.4 ± 2.8^{abcde}
		1.0	17.1 ± 2.5^{cdefghi}
		1.5	15.8 ± 3.6^{abcdefgh}
	AS	0.0	12.8 ± 1.5^{abcd}
		0.5	15.2 ± 6.5^{abcdefgh}
		1.0	19.2 ± 7.9^{cdefghi}
		1.5	18.2 ± 0.8^{cdefghi}
	IM	0.0	21.4 ± 2.7^{hi}
		0.5	19.4 ± 6.1^{defghi}
		1.0	17.7 ± 2.3^{cdefghi}
		1.5	19.4 ± 2.2^{efghi}
Grape Pomace	Control	0.0	19.1 ± 4.0^{cdefghi}
		0.5	20.2 ± 4.3^{fghi}
		1.0	18.6 ± 1.0^{cdefghi}
		1.5	20.3 ± 3.0^{ghi}
	AS	0.0	19.2 ± 3.4^{cdefghi}
		0.5	16.9 ± 2.0^{bcdefgh}
		1.0	14.0 ± 2.5^{abcdefg}
		1.5	15.4 ± 1.6^{abcdefgh}
	IM	0.0	16.0 ± 2.1^{abcdefgh}
		0.5	13.7 ± 2.1^{abcdef}
		1.0	14.9 ± 3.6^{abcdefgh}
		1.5	14.9 ± 2.2^{abcdefgh}
BS	Control	0.0	12.6 ± 1.0^{abc}
		0.5	21.0 ± 2.5^{hi}
		1.0	10.5 ± 1.0^{ab}
		1.5	19.2 ± 1.2^{defghi}
	AS	0.0	12.8 ± 1.5^{abcd}
		0.5	15.7 ± 1.5^{abcdefgh}
		1.0	10.2 ± 1.5^{a}
		1.5	19.1 ± 4.4^{cdefghi}
	IM	0.0	16.0 ± 2.1^{abcdefgh}
		0.5	23.5 ± 4.8^{i}
		1.0	18.4 ± 3.1^{cdefghi}
		1.5	19.1 ± 3.6^{cdefghi}

Key: Results are expressed as mean ± standard deviation (SD). Results followed by same lowercase letter(s) in the column of cutting force do not differ significantly ($p > 0.05$); African spice: AS; industrial marinade/pickle: IM; and Baikal skullcap: BS.

Typically, at the post-slaughter stage of any given broiler chicken, a cascade of lipid peroxidation events takes place and continues even after the application of thermal processing (on the resultant carcass/meat) [54]. At slaughter, the interruption of the blood flow specifically halts the metabolic processes, which results in the development of oxidative rancidity that directly cumulates to the catalyzed phospholipids via heme proteins [54]. Figure 5 shows the various marinated oven-grilled chicken breast samples that obtained a wide range of TBARS values, both before (with minimum TBARS = 3.55 ± 0.13 MDA/kg of the control BS at 1 and 1.5%; maximum TBARS = 12.27 ± 0.00 MDA/kg of the AS + CP 1.5%) and after oven-grilling (with minimum TBARS = 3.32 ± 0.06 MDA/kg of the control BS at 1.5%; maximum TBARS = 12.27 ± 0.00 MDA/kg of the IM + BS 1.5%). Figure 5 also shows that the oven-grilling process momentarily increased the TBARS values of some of the marinated chicken breast meat samples, despite the fluctuating values when both the AS and IM were incorporated. Compared to raw meat, pre-prepared meat products, particularly those submitted to thermal processing, are considered more susceptible to lipid oxidation [54]. Higher temperatures from thermal processing such as with oven-grilling probably progress the release of oxygen, heme, and iron, which by inducing the production of free radicals subsequently kickstart the development of undesirable off-odors/flavors [54]. The process of lipid peroxidation generates oxygen free radicals that decrease food quality and shelf-time, which would require the promising effects of antioxidants, especially those capable of suppressing oxidative stress [34]. Thus, incorporating such marinade variants as either the BS, CP, or GP concentrations reported herein should capably provide available antioxidant potentials. For instance, GP, whether from the contexts of extractable (anthocyanins, flavonols, flavan-3-ols, and phenolic acids) and non-extractable polyphenols (polymeric proanthocyanidins and high molecular weight hydrolyzable tannins), should have the capacity to scavenge radicals, and help prevent the onset of rancidity [55].

Figure 6 shows that the cooking weight loss varied considerably between a minimum of ~12.31% (AS + BS 1.0% conc.) and a maximum of ~26.67% (IM alone). Compared to the control, incorporating AS reduced the cooking weight loss of the various marinated oven-grilled chicken breast samples, but much less for the IM. The degree of cooking weight loss, dependent on the cooking time and the temperature band, further underpins the potential of oven-grill heat temperatures to not only expel the moisture thereof, but more so to modify the textural properties [28]. In the various marinated oven-grilled chicken breast meat samples herein, the cumulative impact of all the (above-mentioned) detected lipid oxidation (TBARS), cooking weight loss, and pH differences would have likely influenced the color [42,47]. Table 3a–c shows that, without incorporating either AS or IM, the $L^* a^* b^*$ color of the various oven-grilled chicken breast meat samples differed significantly ($p < 0.05$) with the BS, CP, and GP concentration increments. The $L^* a^* b^*$ color obtained varying ranges, from ~42.56 to ~83.30 at L^*, from ~2.55 to ~5.80 at the a^*, and from ~2.36 to ~29.05 at the b^* color scales. Further, incorporating either the AS or IM continued to produce significant differences ($p < 0.05$) in the $L^* a^* b^*$ color values. Potentially, the oven-grilling activity contributed to pushing the $L^* a^* b^*$ color of the various marinated chicken breast meat samples herein towards the extreme values, either negatively or positively. Adding together the differences in the connective tissues, alongside the ability of myofibrillar and soluble proteins to bring about textural changes [56], when the heat temperatures such as those coming from an oven-grill facility exceeding the 100 °C mark are applied to an animal meat product, an irreversible denaturation of the heme proteins (i.e., hemoglobin and myoglobin) that likely initiate structural changes can occur, which might result in lightening the color [57].

In Table 4, the incorporation of either AS or IM, together with either increased CP, GP, or BS concentrations to form a herbal mix, produced textural cutting force fluctuations that showed several trends. For instance, incorporating the AS with either increased CP, GP, or BS concentration(s) appeared to initially reduce the cutting force compared to the control, which may well have been stabilizing the fluctuation; however, incorporating the IM with either increased CP, GP, or BS concentration(s) could have produced an initial greater cutting force, with more for the CP, which seemingly represented an increasing trend. Istrati et al. [11] understood that marination could potentially decrease a meat muscle's adhesiveness, chewiness, cohesiveness, hardness, and springiness, and at the same time, increase that of its tenderness, regardless of the applied method and ageing. Sokołowicz et al. [12] believed that, besides the brightness of (chicken breast) meat to corroborate the pH values, the sour nature of marinades and the overall impact of antioxidants would potentially influence the textural properties.

4. Conclusions

This current work has investigated the antioxidant, organoleptic, and physicochemical changes in different marinated oven-grilled chicken breast meat. For emphasis, the chicken breast meat samples were secured from broilers farmed in Poland. Results showed that the CP, GP, and BS concentration increases would not necessarily go along with the ABTS, DPPH, and FRAP despite changes in the pH, cooking weight loss, L^* a^* b^* color and cutting force values, even after incorporating either AS or IM. Establishing specific organoleptic sensory and texture profile trends across increasing CP, GP, and BS concentrations for the various marinated oven-grilled chicken breast meat samples proved challenging. Holistically, this current work provides useful information about some key quality attributes consumers could anticipate in marinated oven-grilled chicken breast meat shortly after preparation/processing. Despite that this current study was unable to delineate the best marinated oven-grilled chicken breast meat, the authors herein are convinced that an oven-grilling approach is promising to moderate the antioxidant, organoleptic, and physicochemical value ranges of various (marinated oven-grilled chicken breast meat) samples. The shelf-life capacity of the oven-grill technique should be the target of future study, which would require subjecting various (oven-grilled) marinated chicken breast meat samples to different packaging and refrigerated storage conditions. Another future work could employ advanced techniques so as to identify the various bioactive compounds present in marinades, which would provide the foundation to further examine/understand their underlying molecular mechanisms that take place when producing oven-grilled marinated chicken breast meat samples.

Author Contributions: Conceptualization, C.O.R.O. and M.K.; Data curation, C.O.R.O., S.J., K.L. and M.K.; Formal analysis, C.O.R.O., S.J., K.L. and M.K.; Funding acquisition, C.O.R.O., S.J., K.L. and M.K.; Investigation, C.O.R.O., S.J. and K.L.; Methodology, C.O.R.O., S.J., K.L. and M.K.; Project administration, M.K.; Software, S.J. and K.L.; Supervision, M.K. and R.P.F.G.; Validation, S.J., K.L., R.P.F.G.; Visualization, S.J., K.L. and R.P.F.G.; Writing—original draft, C.O.R.O. and M.K.; Writing—review and editing, C.O.R.O. and R.P.F.G. All authors have read and agreed to the published version of the manuscript.

Funding: The publication was financed by the Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wrocław University of Environmental and Life Sciences, Wrocław-Poland.

Institutional Review Board Statement: Ethics approval was not required for this study because the chicken breast meat samples were purchased directly from local retailers.

Informed Consent Statement: Verbal consent was taken prior to the panelists' voluntary participation in the organoleptic sensory and textural profile evaluation.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Authors C.O.R.O., K.L., S.J., and M.K. acknowledge the financial support from Wroclaw University of Environmental and Life Sciences, Poland. Author R.P.F.G. acknowledges the financial support from Polytechnic Institute of Viseu, Portugal.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sas, A. Production of Meat and Meat Products in Poland 2018–2021, by Product Type, Agriculture-Farming, Statistica. 2022. Available online: https://www.statista.com/statistics/1125806/poland-production-of-meat-and-meat-products/ (accessed on 11 October 2022).
2. Adamski, M.; Kuzniacka, J.; Milczewska, N. Preferences of consumers for choosing poultry meat. *Pol. J. Natur. Sci.* **2017**, *32*, 261–271.
3. Sosnówka-Czajka, E.; Skomorucha, I.; Muchacka, R. Effect of Organic Production System on the Performance and Meat Quality of Two Purebred Slow-Growing Chicken Breeds. *Ann. Anim. Sci.* **2017**, *17*, 1197–1213. [CrossRef]
4. Pawłowska, J.; Sosnówka-Czajka, E. Factors affecting chick quality in Poland. *World's Poult. Sci. J.* **2019**, *75*, 621–632. [CrossRef]
5. Kokoszyński, D.; Żochowska-Kujawska, J.; Kotowicz, M.; Sobczak, M.; Piwczyński, D.; Stęczny, K.; Majrowska, M.; Saleh, M. Carcass characteristics and selected meat quality traits from commercial broiler chickens of different origin. *Anim. Sci. J.* **2022**, *93*, e13709. [CrossRef]
6. Jaturasitha, S.; Kayan, A.; Wicke, M. Carcass and meat characteristics of male chickens between Thai indigenous compared with improved layer breeds and their crossbred. *Arch. Anim. Breed.* **2008**, *51*, 283–294. [CrossRef]
7. De Liu, X.; Jayasena, D.D.; Jung, Y.; Jung, S.; Kang, B.S.; Heo, K.N.; Lee, J.H.; Jo, C. Differential Proteome Analysis of Breast and Thigh Muscles between Korean Native Chickens and Commercial Broilers. *Asian-Australas. J. Anim. Sci.* **2012**, *25*, 895–902. [CrossRef]
8. Swatland, H. How pH causes paleness or darkness in chicken breast meat. *Meat Sci.* **2008**, *80*, 396–400. [CrossRef]
9. Martini, S.; Cattivelli, A.; Conte, A.; Tagliazucchi, D. Black, green, and pink pepper affect differently lipid oxidation during cooking and in vitro digestion of meat. *Food Chem.* **2021**, *350*, 129246. [CrossRef]
10. Zhang, H.; Wu, J.; Guo, X. Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality. *Food Sci. Hum. Wellness* **2016**, *5*, 39–48. [CrossRef]
11. Istrati, D.; Ciuciu, A.M.; Vizireanu, C.; Ionescu, A.; Carballo, J. Impact of Spices and Wine-Based Marinades on Tenderness, Fragmentation of Myofibrillar Proteins and Color Stability in Bovine B iceps Femoris Muscle. *J. Texture Stud.* **2015**, *46*, 455–466. [CrossRef]
12. Sokołowicz, Z.; Augustyńska-Prejsnar, A.; Krawczyk, J.; Kačániová, M.; Kluz, M.; Hanus, P.; Topczewska, J. Technological and Sensory Quality and Microbiological Safety of RIR Chicken Breast Meat Marinated with Fermented Milk Products. *Animals* **2021**, *11*, 3282. [CrossRef] [PubMed]
13. Cheok, C.; Chin, N.; Yusof, Y.; Kamal, S.M.M.; Sazili, A. Effect of marinating temperatures on physical changes of traditionally marinated beef satay. *J. Food Process. Preserv.* **2011**, *35*, 474–482. [CrossRef]
14. Lemos, A.; Nunes, D.; Viana, A. Optimization of the still-marinating process of chicken parts. *Meat Sci.* **1999**, *52*, 227–234. [CrossRef] [PubMed]
15. Al-Dalali, S.; Li, C.; Xu, B. Evaluation of the effect of marination in different seasoning recipes on the flavor profile of roasted beef meat via chemical and sensory analysis. *J. Food Biochem.* **2021**, *46*, e13962. [CrossRef] [PubMed]
16. Salmon, C.; Knize, M.; Felton, J. Effects of marinating on heterocyclic amine carcinogen formation in grilled chicken. *Food Chem. Toxicol.* **1997**, *35*, 433–441. [CrossRef]
17. Shahidi, F.; Hossain, A. Bioactives in spices, and spice oleoresins: Phytochemicals and their beneficial effects in food preservation and health promotion. *J. Food Bioact.* **2018**, *3*, 8–75. [CrossRef]
18. Jalali, M.; Mahmoodi, M.; Moosavian, S.P.; Jalali, R.; Ferns, G.; Mosallanezhad, A.; Imanieh, M.H.; Mosallanezhad, Z. The effects of ginger supplementation on markers of inflammatory and oxidative stress: A systematic review and meta-analysis of clinical trials. *Phytother. Res.* **2020**, *34*, 1723–1733. [CrossRef]
19. Roopchand, D.E.; Krueger, C.G.; Moskal, K.; Fridlender, B.; Lila, M.A.; Raskin, I. Food-compatible method for the efficient extraction and stabilization of cranberry pomace polyphenols. *Food Chem.* **2013**, *141*, 3664–3669. [CrossRef]
20. Teplá, J.L.; Dostálová, T.; Lužová, D.; Rožnovská, J.; Přichystalová, L.; Kalhotka, L.; Dvořák, L.; Sýkora, V.; Šustová, K. Antimicrobial effects of selected plant extracts on the shelf life of goat whey. *MendelNet* **2013**, 614–620. Available online: https://mnet.mendelu.cz/mendelnet2013/articles/44_tepla_877.pdf (accessed on 1 December 2022).
21. Yu, J.; Ahmedna, M.; Goktepe, I. Effects of processing methods and extraction solvents on concentration and antioxidant activity of peanut skin phenolics. *Food Chem.* **2005**, *90*, 199–206. [CrossRef]
22. Zhang, Y.; Henning, S.M.; Lee, R.-P.; Huang, J.; Zerlin, A.; Li, Z.; Heber, D. Turmeric and black pepper spices decrease lipid peroxidation in meat patties during cooking. *Int. J. Food Sci. Nutr.* **2015**, *66*, 260–265. [CrossRef] [PubMed]
23. Awuchi, C.G.; Okpala, C.O.R. Natural nutraceuticals, especially functional foods, their major bioactive components, formulation, and health benefits for disease prevention-An overview. *J. Food Bioact.* **2022**, *19*, 97–123. [CrossRef]
24. Raut, S.S.; Rindhe, S.N.; Verma, S.K.; Swami, J.N.; Mundhe, B.L.; Rayeesul, I. Effect of Acidulant on Chicken Pickle Incorporated with Poultry By-products. *J. Meat Sci. Technol.* **2015**, *3*, 12–17.
25. Viegas, O.; Amaro, L.F.; Ferreira, I.M.; Pinho, O. Inhibitory Effect of Antioxidant-Rich Marinades on the Formation of Heterocyclic Aromatic Amines in Pan-Fried Beef. *J. Agric. Food Chem.* **2012**, *60*, 6235–6240. [CrossRef]
26. Richardson, P. (Ed.) *Improving the Thermal Processing of Foods*; Woodhead Publishing Ltd.: Cambridge, UK, 2004; p. 520, ISBN 978-1855737303.
27. Schröder, M.J. *Food Quality and Consumer Value: Delivering Food that Satisfies*; Springer: Berlin, Germany, 2003; p. 150, ISBN 3540439145.

28. Ježek, F.; Kameník, J.; Macharáčková, B.; Bogdanovičová, K.; Bednář, J. Cooking of meat: Effect on texture, cooking loss and microbiological quality—A review. *Acta Vet. Brno* **2020**, *88*, 487–496. [CrossRef]
29. Beckett, F. *Sausage & Mash*; Bloomsbury Publishing: London, UK, 2012; p. 160, ISBN 9781408187760.
30. Liao, G.; Wang, G.; Xu, X.; Zhou, G. Effect of cooking methods on the formation of heterocyclic aromatic amines in chicken and duck breast. *Meat Sci.* **2010**, *85*, 149–154. [CrossRef]
31. Farhadian, A.; Jinap, S.; Abas, F.; Sakar, Z.I. Determination of polycyclic aromatic hydrocarbons in grilled meat. *Food Control* **2010**, *21*, 606–610. [CrossRef]
32. Kerth, C.R.; Blair-Kerth, L.K.; Jones, W.R. Warner-Bratzler shear force repeatability in beef longissimus steaks cooked with a convection oven, broiler, or clam-shell grill. *J. Food Sci.* **2003**, *68*, 668–669. [CrossRef]
33. Khan, M.I.; Min, J.-S.; Lee, S.-O.; Yim, D.G.; Seol, K.-H.; Lee, M.; Jo, C. Cooking, storage, and reheating effect on the formation of cholesterol oxidation products in processed meat products. *Lipids Health Dis.* **2015**, *14*, 89. [CrossRef]
34. Bai, W.K.; Zhang, F.J.; He, T.J.; Su, P.W.; Ying, X.Z.; Zhang, L.L.; Wang, T. Dietary pro-biotic Bacillus subtilis strain fmbj increases antioxidant capacity and oxidative stability of chicken breast meat during storage. *PLoS ONE* **2016**, *11*, e0167339. [CrossRef]
35. Lengkidworraphiphat, P.; Wongpoomchai, R.; Taya, S.; Jaturasitha, S. Effect of genotypes on macronutrients and antioxidant capacity of chicken breast meat. *Asian-Australas. J. Anim. Sci.* **2020**, *33*, 1817–1823. [CrossRef] [PubMed]
36. Augustyńska-Prejsnar, A.; Ormian, M.; Sokołowicz, Z. Physicochemical and Sensory Properties of Broiler Chicken Breast Meat Stored Frozen and Thawed Using Various Methods. *J. Food Qual.* **2018**, *2018*, 6754070. [CrossRef]
37. Brambila, G.S.; Bowker, B.C.; Zhuang, H. Comparison of sensory texture attributes of broiler breast fillets with different degrees of white striping. *Poult. Sci.* **2016**, *95*, 2472–2476. [CrossRef]
38. Akmakçı, S.; Topdaş, E.F.; Kalın, P.; Han, H.; Şekerci, P.; Köse, L.P.; Gülçin, İ. Antioxidant capacity and functionality of oleaster (Elaeagnus angustifolia L.) flour and crust in a new kind of fruity ice cream. *Int. J. Food Sci. Technol.* **2015**, *50*, 472–481. [CrossRef]
39. Civille, G.V.; Carr, B.T. *Sensory Evaluation Techniques*, 5th ed.; CRC Press: Boca Raton, FL, USA, 2015; p. 632, ISBN 13-9781482216905.
40. Barido, F.H.; Lee, S.K. Effect of detoxified Rhus verniciflua extract on oxidative stability and quality improvement of raw chicken breast during cold storage. *J. Anim. Sci. Technol.* **2022**, *64*, 380–395. [CrossRef] [PubMed]
41. Luciano, G.; Moloney, A.P.; Priolo, A.; Röhrle, F.T.; Vasta, V.; Biondi, L.; López-Andrés, P.; Grasso, S.; Monahan, F.J. Vitamin E and polyunsaturated fatty acids in bovine muscle and the oxidative stability of beef from cattle receiving grass or concentrate-based rations1. *J. Anim. Sci.* **2011**, *89*, 3759–3768. [CrossRef] [PubMed]
42. Ali, S.; Kang, G.-H.; Yang, H.-S.; Jeong, J.-Y.; Hwang, Y.-H.; Park, G.-B.; Joo, S.-T. A Comparison of Meat Characteristics between Duck and Chicken Breast. *Asian-Australas. J. Anim. Sci.* **2007**, *20*, 1002–1006. [CrossRef]
43. Kopec, W.; Jamroz, D.; Wiliczkiewicz, A.; Biazik, E.; Pudlo, A.; Korzeniowska, M.; Hikawczuk, T.; Skiba, T. Antioxidative Characteristics of Chicken Breast Meat and Blood after Diet Supplementation with Carnosine, L-histidine, and β-alanine. *Antioxidants* **2020**, *9*, 1093. [CrossRef]
44. Augustyńska-Prejsnar, A.; Ormian, M.; Sokołowicz, Z. The influence of frozen storage duration and thawing methods on the meat quality of broiler chickens. *Apar. Badaw. i Dydakt.* **2017**, *22*, 253–259.
45. Floegel, A.; Kim, D.O.; Chung, S.J.; Song, W.O.; Fernandez, M.L.; Bruno, R.S.; Koo, S.I.; Chun, O.K. Development and validation of an algorithm to establish a total antioxidant capacity database of the US diet. *Int. J. Food Sci. Nutr.* **2010**, *61*, 600–623. [CrossRef]
46. Sáyago-Ayerdi, S.; Brenes, A.; Viveros, A.; Goñi, I. Antioxidative effect of dietary grape pomace concentrate on lipid oxidation of chilled and long-term frozen stored chicken patties. *Meat Sci.* **2009**, *83*, 528–533. [CrossRef] [PubMed]
47. Kim, J.; Bang, J.; Beuchat, L.R.; Kim, H.; Ryu, J.-H. Controlled fermentation of kimchi using naturally occurring antimicrobial agents. *Food Microbiol.* **2012**, *32*, 20–31. [CrossRef] [PubMed]
48. Lee, K.J.; Jung, P.M.; Oh, Y.-C.; Song, N.-Y.; Kim, T.; Ma, J.Y. Extraction and Bioactivity Analysis of Major Flavones Compounds fromScutellaria baicalensisUsing In Vitro Assay and Online Screening HPLC-ABTS System. *J. Anal. Methods Chem.* **2014**, *2014*, 563702. [CrossRef] [PubMed]
49. Smaoui, S.; Ben Hlima, H.; Ghorbel, R. The effect of sodium lactate and lactic acid combinations on the microbial, sensory, and chemical attributes of marinated chicken thigh. *Poult. Sci.* **2012**, *91*, 1473–1481. [CrossRef]
50. Warner, R.; Miller, R.; Ha, M.; Wheeler, T.L.; Dunshea, F.; Li, X.; Wheeler, T. Meat tenderness: Underlying mechanisms, instrumental measurement, and sensory assessment. *Meat Muscle Biol.* **2021**, *4*, 1–25. [CrossRef]
51. Chumngoen, W.; Tan, F.J. Relationships between descriptive sensory attributes and physico-chemical analysis of broiler and Taiwan native chicken breast meat. *Asian-Australas. J. Anim. Sci.* **2015**, *28*, 1028. [CrossRef]
52. Schilling, M.W.; Schilling, J.K.; Claus, J.R.; Marriott, N.G.; Duncan, S.E.; Wang, H. Instrumental texture assessment and consumer acceptability of cooked broiler breasts evaluated using a geometrically uniform-shaped sample. *J. Muscle Foods* **2003**, *14*, 11–23. [CrossRef]
53. Chuaynukool, K.; Wattanachant, S.; Siripongvutikorn, S. Chemical and physical properties of raw and cooked spent hen, broiler and Thai indigenous chicken muscles in mixed herbs acidified soup (Tom Yum). *J. Food Technol.* **2007**, *5*, 180–186.
54. Amaral, A.B.; da Silva, M.V.; Lannes, S.C.D.S. Lipid oxidation in meat: Mechanisms and protective factors—A review. *Food Sci. Technol.* **2018**, *38*, 1–15. [CrossRef]
55. Sáyago-Ayerdi, S.; Brenes, A.; Goñi, I. Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. *LWT-Food Sci. Technol.* **2009**, *42*, 971–976. [CrossRef]

56. Murphy, R.Y.; Marks, B.P. Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. *Poult. Sci.* **2000**, *79*, 99–104. [CrossRef] [PubMed]
57. Rabeler, F.; Feyissa, A.H. Kinetic Modeling of Texture and Color Changes During Thermal Treatment of Chicken Breast Meat. *Food Bioprocess Technol.* **2018**, *11*, 1495–1504. [CrossRef]

04 czerwca 2023 r

(miejscowość i data)

Charles Odilichukwu R. OKPALA...

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy ...... *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods, 11(24), 3951*..... mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

04 June 2023.............

data i podpis

Wrocław 03.04.2023

mgr inż. Szymon Juchniewicz
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods, 11(24), 3951* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

3.04.2023 Juchniewicz Szymon

Wrocław 03.04.2023

mgr inż. Katarzyna Leicht
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods, 11(24), 3951* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

03.04.2023, Katarzyna Leicht

dr hab Małgorzata Korzeniowska, prof. uczelni

03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods, 11(24), 3951,* mój wkład polegał na uczestnictwie w konceptualizacji, administrowaniu projektem, nadzorze poprawności oraz walidacji/wizualizacji danych.

....

data i podpis

…Prof Dr. hab. Raquel P.F. Guine…. 01 czerwca 2023 r

imię i nazwisko (miejscowość i data)

Polytechnic Institute of Viseu, Portugal….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy ……*Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2022). Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. Foods, 11(24), 3951*… mój udział współnadzorował prace projektowe, udzielał wglądu w metodologię, uczestniczył w walidacji/ wizualizacji danych oraz w rewizji projektu pracy.

15 May 2023

…………………………

data i podpis

INTERNATIONAL JOURNAL OF FOOD PROPERTIES
2023, VOL. 26, NO. 1, 453–470
https://doi.org/10.1080/10942912.2023.2166952

Taylor & Francis
Taylor & Francis Group

Quality attributes of different marinated oven-grilled pork neck meat

Charles Odilichukwu R Okpala[a,b], Szymon Juchniewicz[a], Katarzyna Leicht[a], Hanna Skendrović[c], Małgorzata Korzeniowska[a], and Raquel P.F. Guiné[d]

[a]Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland; [b]UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia, Athens, GA, USA; [c]Faculty of Food Technology and Biotechnology, University of Zagreb, Zagreb, Croatia; [d]CERNAS Research Centre, Polytechnic Institute of Viseu, Viseu, Portugal

ABSTRACT

Whereas herbs/spices serve as natural preservatives, and thermal processing makes animal meat products edible, combining them should complement each other. Additionally, the application of oven grilling to meat products continues to increase in popularity. However, there is a paucity of relevant published information specific to different marinated oven-grilled pork neck meat. Therefore, the quality attributes of different marinated oven-grilled pork neck meat were investigated, which involved chemical (pH, thiobarbituric acid reactive substance [TBARS], 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) [ABTS], 1,1-diphenyl-2-pierylhydrazy [DPPH], ferric reducing antioxidant power [FRAP]), physical (cooking weight loss, L*a*b* color, and textural cutting force), as well as organoleptic (sensory: flavor, appearance, tenderness, taste, and off-flavor; texture: hardness, chewiness, gumminess, graininess, and greasiness) aspects. In particular, the pork neck meat was procured from a porcine farm in Poland. Different marinated variants comprised constituent 0.5, 1, and 1.5% quantities of cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS) that subsequently incorporated either African spice (AS) or industrial marinade/pickle (IM). Results showed decreases in ABTS, DPPH, FRAP, and TBARS in some marinated oven-grilled pork neck meat samples, alongside pH variations by difference that seemingly associated with increasing concentrations of either CP, BS, or GP, which might not always coincide with L*a*b* color trends as AS and IM were incorporated. Despite the many resemblances ($p > .05$), the sensory aspects fluctuated as textural chewiness, gumminess, and hardness increased in some samples, more evident when incorporating AS compared to IM. Overall, oven-grilling promises to moderate the range values of key quality attributes of different marinated pork neck meat samples in this study.

ARTICLE HISTORY
Received 17 October 2022
Revised 02 January 2023
Accepted 05 January 2023

KEYWORDS
Pork neck meat; Marination; Herbs and spices; Muscle value; Thermal processing

Introduction

Pork accounted for about 36% of global meat production as of 2013, which has placed this animal food product among the most widely consumed, as it has accounted for 110 million metric tonnes (mmt), and surpassed both beef (67 mmt) and chicken (104 mmt). China as of 2020 topped the global pork production, followed by European Union (EU), before United States[1,2] . In 2016, the pork production in the EU was recorded to reach 23.4 million tonnes, which translated to 45.9 kg per inhabitant.[3] Indeed, the demand for pork meat gradually increases with global population, which has been poised

CONTACT Charles Odilichukwu R Okpala charlesokpala@gmail.com; Małgorzata Korzeniowska malgorzata.korzeniowska@upwr.edu.pl Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland

to persist into the next few decades.[1,4] Specific to Poland, pork maintains a strong position in meat consumption, having recorded 21.8 million slaughtered pigs in 2016, which was largely driven by supply chain elements of procurement, processing, and distribution.[3–5] Moreover, the various stages of pig production, from the breeding choices, through the on-site farm management/slaughter processes, to culinary aspects, remain very crucial to realize high-quality pork.[6] Notable aspects of pork meat processing, largely three-fold, include slaughtering, meat cutting, and further processing. With respect to food service, the primal aspects of pork meat cutting/processing include leg, loin, belly, and shoulder.[7] Moreover, when evaluating Poland's domestic pork processing activity, Szymańska[5] reported the following trends: meat products> cutting plants> slaughterhouses> meat mincing>mechanically separated meat.

Compared to beef, the pork carcass/meat is among USDA considered red meat that possesses ample protein, relatively high thiamin (vitamin B1), cholesterol, and saturated fat, with low myoglobin contents[8–11] . There are some ante-/postmortem-associated biochemical/storage-related characteristics that contribute to influencing pork quality[12,13] . Like other meat products, moreover, the accelerated postmortem glycolysis that is triggered by lipid breakdown products post-slaughter typically brings about the process of quality deterioration.[14] In addition to refrigerated storage that helps to curtail as well as manage both lipid breakdown and microbial proliferation, many pork consumers/stakeholders especially those of small-medium scale enterprises continually seek for enhanced/low-cost processing and shelf-life extension strategies, for example, the use of natural preservatives. Moreover, pork quality has been associated with such conditions as pale, soft, and exudative (PSE), which reflects both appearance and physical condition(s).[15] More so, pork quality would equally depend on such factors as the effect(s) of diet and exercise (of the pig), changes associated with postmortem/rigor mortis, muscle structure and resultant water holding capacity, fiber type (of muscle) as well as processing yield of the overall (pork)meat.[15]

In recent times, natural preservatives such as marinades are increasingly being pursued in many parts of the globe, especially their application to meat products, which has been largely focused to enhance various quality characteristics[16–18] . The process at which meat muscle assimilates the marinade would depend on (meat) type, marination technique, as well as duration of the (marination) process.[19] The most common marination process involves immersing the meat products in desired slurry/solution mix that can involve such components/ingredients like Baikal skullcap, cranberry pomace, herbs/spices, ginger, peanut, black/regular pepper, etc.,[14,16–18,20–23] which would deliver such bioactive/health-promoting compounds as beneficial phenolic/phenols, flavonoids, polyphenols, etc.[14,23–25] Moreover, for animal meat products to become edible, there must be submitted to heat/thermal treatment, the latter which has helped to ensure decreased microbial proliferation and enhanced flavor/texture. Examples of thermal processing include aseptic processing, cook-chill, grilling/roasting, laser-based packaging, ohmic heating, etc[26–28] . Despite the well-known difference between roasting (indirect heating method) and grilling (direct heating method), the physical characteristic outcomes post-application of both methods regards animal meat products might resemble.

There is increasing interest among researchers in grilling, which provides heat temperatures that are capable of delivering direct/radiant dry heat transferred by conduction. Additionally, a typical example increasingly employed across households globally is the oven-grill approach,[28–30] which uses a facility that is widely available and commercially. This has made the application of oven grilling to animal meat products to increase in popularity.[31–33] Despite this, there is a paucity of relevant published information specific to different marinated oven-grilled pork neck meat. Given that herbs/spices would capably serve as natural preservatives and considering the benefits thermal processing avails to meat products, it is a useful rationale to understand the effects oven-grill would have on a given marinated pork neck meat, especially from both consumer appeal and quality value standpoints, prior to storage considerations. To supplement existing information, therefore, this current work investigated the quality attributes of different marinated oven-grilled pork neck meat. In particular, the pork neck meat has been procured from a porcine farm in Poland.

Materials and methods

Schematic overview of experimental program

The schematic overview of the experimental program, which depicts the major stages, from the procurement of pork neck meat samples, preparation of marinade variants, through the oven-grilling activity, up to the various analytical measurements, is shown in Figure 1. For emphasis, this work attempted to understand the effects oven-grilling would have on the quality attributes of different marinated pork neck meat. The marinades involved ground constituents of cranberry pomace, grape pomace, and Baikal skullcap, which subsequently incorporated African spice, and Industrial marinade/pickle. The quality attributes involved chemical (pH, thiobarbituric acid reactive substance [TBARS], 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) [ABTS], 1,1-diphenyl-2-pieryl-hydrazy [DPPH], ferric reducing antioxidant power [FRAP]), physical (cooking weight loss, L*a*b* color, and textural cutting force), as well as organoleptic (sensory = flavor, appearance, tenderness, taste and flavor; texture = hardness, chewiness, gumminess, graininess, and greasiness) aspects. The chemicals/reagents used were of analytical grade standard. All conducted laboratory procedures adhered to the standard guidelines set out by the Department of Functional Food Product Development, Wroclaw University of Environmental and Life Sciences, Poland.

Procurement, and further preparation of pork neck meat samples

Freshly processed pork neck meat were supplied shortly after slaughter and packaging by a reputable local certified porcine retailer that supplies the Wroclaw's Lower Silesia region. The dressed carcasses (~ 20 kg) placed in iced packed poly-boxes were received at the Department of Functional Food Products Development, Wroclaw University of Environmental and Life Sciences (Poland). Upon arrival, the pork neck samples were further prepared as described by Kim et al.,[34] by cutting them

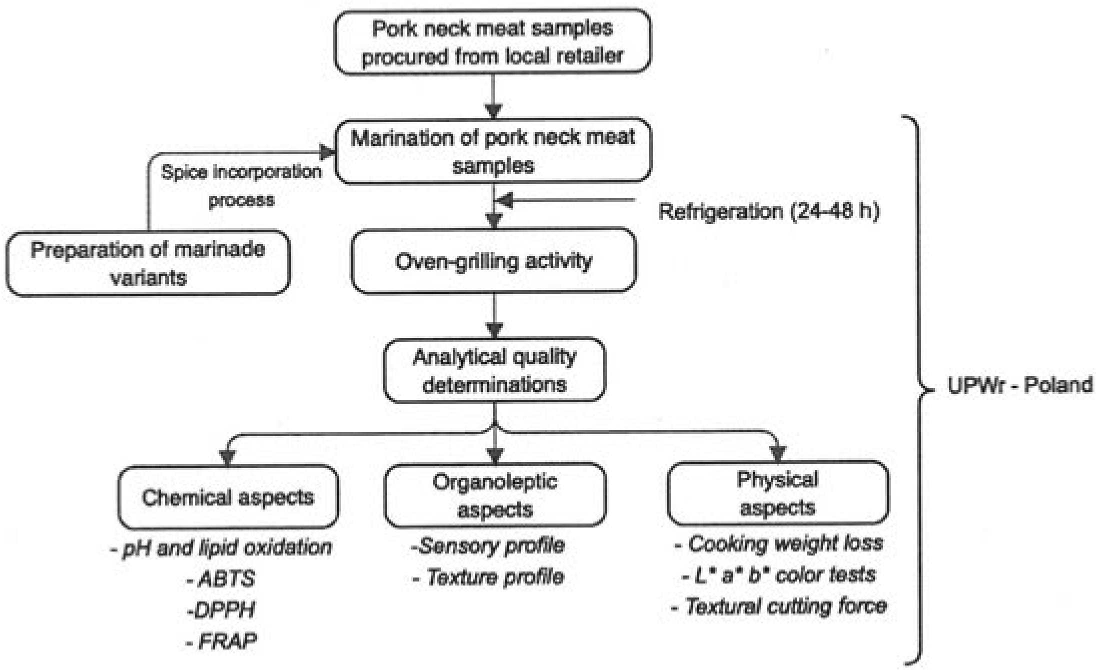

Figure 1. The schematic overview of the experimental program, showing the key stages, from the procurement of pork neck meat samples, preparation of marinade variants, through oven-grilling activity, subsequently analytical measurements. ABTS = 2,2′-Azinobis-(3-ethylbenzthiazoline-6-sulfonate); DPPH = 1,1-diphenyl-2-pierylhydrazy (radical scavenging activity); FRAP = ferric reducing antioxidant power; UPWr = Uniwersytet Przyrodniczy we Wrocławiu (Wroclaw University of Environmental and Life Sciences-Poland).

into equivalent pieces of approximate thickness (9 × 9 × 3 cm), and subsequently placed in cold room refrigeration (~2°C), after which marination and subsequently oven-grilling were performed.

Preparation of marinades, and marination variants

The marinade preparation involved salt (1.6 g), ground cranberry pomace (CP), grape pomace (GP), and Baikal Skullcap (BS) at 0.5%, 1%, and 1.5% constituent quantities, which subsequently incorporated either African spice (AS) or Industrial marinade/pickle (IM) (4 g). The usage of CP, GP, and BS marinades, given their bioactive constituents, is to improve the nutritional status of the pork neck meat. The African spice product (Fresh and Tasty Kebab Powder) were from Fresh and Tasty Farms Ltd (Accra-North, Ghana) prepared according to the quality standards of Food and Drugs Authority (FDA) Ghana, with the label comprising ingredients peanut, ginger, as well as black/regular pepper. The use of this specific African spice product is believed to gain interest in barbecues across Poland. The industrial marinade/pickle (Marinate do mięs) product was from Regis(R) Food Technology (Regis sp. z o.o., Kraków-Poland) prepared according to the quality standards of International Organization for Standardization (ISO), British Retail Consortium (BRC), and International Food Standard (IFS), with the label comprising ingredients as thyme, oregano, rosemary, marjoram, and parsley. Also, this specific industrial marinade/pickle product is believed to have an established reputation in Poland and elsewhere in the EU.

The marination variants, which comprised increments of CP, GP, and BS concentrations that incorporated either AS or IM, were implemented as follows: 1) control (antioxidant additive % = 0.0); 2) control (antioxidant additive % = 0.5); 3) control (antioxidant additive % = 1.0); 4) control (antioxidant additive % = 1.5); 5) AS (antioxidant additive % = 0.0); 6) AS (antioxidant additive % = 0.5); 7) AS (antioxidant additive % = 1.0); 8) AS (antioxidant additive % = 1.5); 9) IM (antioxidant additive % = 0.0); 10) IM (antioxidant additive % = 0.5); 11) IM (antioxidant additive % = 1.0); 12) IM (antioxidant additive % = 1.5). As described by Sokołowicz et al.[18] with some modifications, the immersion method was adapted to marinate the pork neck meat samples. We used plastic containers approved for contact with food to prepare the marinade using the 1:2 ratio to reflect the weight of meat (g) and marinade volume (mL). The pork meat samples were sufficiently dipped in the marinade variants for 24 h period. When immersion time was completed, marinated samples were allowed to drain (5 min), thereafter placed in folded foiled packages, and made ready for oven-grilling activity.

Oven-grilling procedure

The oven-grilling activity resembling the description given by Salmon, Knize, and Felton[35] with some modifications was applied to the various marinated pork neck samples. The oven-grilling process was specifically conducted using a commercially available electric hot air convection (oven) type facility (CAMRY CR 6017, Serwis Centralny Camry, Warszawa, Poland). The oven-grilling operated with 2200 W power, and temperature set at 180°C. In the pre-heated oven, the pork neck meat samples, evenly spaced on grill rack, received heating of the set temperature that was evenly distributed from the bottom as well as top. During the cooking process, the oven-grill facility remained closed, and only opened on either the placement or removal of samples. Also, the internal temperature of the pork neck meat samples was checked routinely to ensure it roughly maintained at 75°C. The cooking time was constant (5 min), and was applied to all the marinated samples. When completed, the pork neck meat samples were allowed to cool (10 min) at ambient temperature, and thereafter refrigerated (4°C) during which analytical determinations were performed within 24 h period.

Determination of chemical aspects

The pH measurement slightly modified from Barido and Lee[36] specifically taken before and after the oven-grilling activity. Roughly 5 g sample and 45 mL of distilled water were mixed using a homogenizer (PH91, SMT Chiba, Japan) at 10,000 rpm, for 1 min, thereafter tested using pH meter (HI 99163 Hanna Instrument Company, Vöhringen, Germany) that had been calibrated by buffer solutions (approximate pH 4.0, 7.0, and 9.0).

The thiobarbituric acid reactive substance (TBARS) measurement has been slightly modified from Luciano et al.[37] and specifically determined before and after the oven-grilling process. With the help of stomacher, the pork neck meat samples (1.0 g) were homogenized with 10 mL of 10% trichloroacetic acid (TCA) for 1 min, thereafter centrifugation at 4000 × g (MPW-351 R refrigerated, MPW Med. instruments Warszawa, Poland), after which the emergent mix has been subject to filtration (Whatman #1 filter paper). Next, 2 mL of supernatant was transferred to 2 mL of 0.06 M thiobarbituric acid. The reaction mixture was submitted to water bath at 100°C for 40 min, then cooled under ice-water bath (~ 2 min). Calibration curve was prepared using 1,1,3,3-tetraethoxypropane TCA (standard solution). The samples were finally analyzed, reading the absorbance at 532 nm via UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, Massachusetts-USA). The TBARS values were reported as mg of malondialdehyde (MDA) per kg of meat sample.

The determination of 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) ($ABTS^+$) radical scavenging activity has been slightly modified from Bai et al.[38] The $ABTS^+$ has been produced by mixing 7 mM of stock solution with 2.45 mM $K_2S_2O_8$, thereafter incubated in darkness at 25°C for 12–16 h. From this, 990 μL of $ABTS^+$ solution was mixed with 10 μL of meat tissue supernatant, thereafter incubated at ambient temperature (~ 25°C) for 6 min. The control comprised 990 μL of $ABTS^+$ solution mixed with 10 μL EtOH 70%. The absorbance was spectrophotometrically measured at 734 nm. The ABTS+ radical scavenging activity values were reported as mM Trolox.

The determination of 1,1-diphenyl-2-pierylhydrazy (DPPH) radical scavenging activity has been slightly modified from Zhang et al.[23] This involved aliquots (20 μL) from meat tissue supernatant vigorously mixed with 200 μL 0.3 mM of ethanolic DPPH radical solution by vortex for 1 min, and subsequently kept in the dark for 30 min under ambient temperature (25°C). The absorbance was recorded against a blank at 517 nm via UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Massachusetts-USA). The DPPH radical scavenging activity values were reported as mM Trolox.

The determination of ferric reducing antioxidant power (FRAP) has been slightly modified from Lengkidworraphiphat et al.[39] Ethanol extracts of pork neck meat sample were prepared using 70% EtOH. The FRAP solution comprised 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ), 20 mM ferric chloride, together with 300 mM sodium acetate buffer (pH 3.6), at a ratio of 1:1:10 (v:v:v), which were subsequently incubated for 30 min at 37°C. Control comprised 3 mL FRAP reagent mixed with 1 mL EtOH. The absorbance of resultant solution was recorded at 593 nm via UV-Vis Spectrophotometer (GENESYS™ 180, ThermoFisher Scientific Inc., Waltham, Massachusetts-USA). The FRAP values were reported as mM/dm^3.

Determination of physical aspects

Cooking weight loss measurement has been slightly modified from Ali et al.[40] Specifically, the samples had been weighed prior to and after oven-grilling, wherein the cooking weight loss depicted cooked sample (B) weight as a percentage of precooked sample (A) weight as shown by the equation below:

$$\text{Cookingloss}(\%) = [(A - B)/(A)] \times 100$$

Color measurements has been slightly modified from Kopec et al.[41], specifically conducted before and after oven-grilling by way of CIE L*a*b* scale (L* = darkness; a* = redness/greenness; and b* = yellowness/blueness) using a Minolta CR-40 reflection colorimeter (Konica Minolta Sensing Europe B.V., NL-3439 MR Nieuwegein-Netherlands). Three individual measurements had been performed on different areas on the pork neck meat surface, after which the readings were collected from the display results via the CIE L*a*b* colorimetric system at real-time.

Textural cutting force measurement has been slightly modified from Augustyńska-Prejsnar, Ormian, and Sokołowicz,[42] which involved measuring the force required to cut a piece of pork neck meat. The cutting force (F-max) instrument was the Zwick/Roell machine (Zwick GmbH & Co. KG, Ulm, Germany), equipped with Warner-Bratzler V-blade knife, head speed of 100 mm/min and initial force of 0.2 N. The portions of pork neck meat samples to be cut had an estimated cross-sectional diameter of 100 mm^2 and length of 50 mm.

Determination of organoleptic aspects

Organoleptic determinations of pork neck meat samples comprised sensorial analysis modified from Augustyńska-Prejsnar, Ormian, and Sokołowicz[43], and textural profiling modified from Brambila, Bowker, and Zhuang.[44] Sensory panelists comprised ten (10) staff and graduate students of the Department of Functional Food Products Development, Wrocław University of Environmental and Life Sciences (Poland), already familiar with the evaluation criteria to differentiate the levels of sensorial flavor, appearance, tenderness, taste, and off-flavor, as well as textural hardness, chewiness, gumminess, and graininess. The verbal consent taken prior to the sensory evaluation. Panelists' participation was voluntary, and no name/gender was reported to ensure privacy. Panelists' performed the organoleptic evaluation in well-ventilated room of neutral color, proper lighting, and distraction-free. For the organoleptic assessment, the evenly cut samples already cooled to 20°C ± 2°C were placed in coded white plastic plates. For the sensorial tests, each panelist used warm water to cleanse taste palates between samples, to ensure the previous evaluation did not affect the (taste of the) new one, consistent with Çakmakçı et al.[45] The panelists reported the findings of coded samples based on 0–5 sensory scale (1 point being the lowest score and 5 points being the highest), and 0 to 15 texture scale (1 point being the lowest score and 15 points being the highest).[46]

Statistical analysis

The data, independently generated from different samples and based on minimum of two determinations, were submitted to analysis of variance (ANOVA). The statistical significance was set at $p < .05$ (95% confidence level). Statistica 13.0 software (StatSoft GmbH, Hamburg Germany) was used to run the data.

Results and discussion

Changes in chemical aspects

Chemical aspects (specific to pH, ABTS, DPPH, FRAP, and TBARS) of different marinated oven-grilled pork neck meat were investigated (Figures 2–4, and Table 1). Across all samples, considering oven-grilling and antioxidant additives, the pH, TBARS, ABTS, DPPH, and FRAP values obtained varying ranges, from minimum (pH = ~5.22 at CP control pre-oven grill; TBARS = 4.27 ± 0.13 mg MDA/kg at AS + BS 0.5% pre-oven grill; ABTS = 1.80 ± 0.04 mM/Trolox at AS + BS 1.5%; DPPH = 0.21 ± 0.02 mM/Trolox at AS Control; FRAP = .07 ± 0.00 mM/dm^3 at AS + BS 1% or Control + BS 1%) to maximum (pH = ~6.79 at BS Control pre-oven grill; TBARS = 22.09 ± 0.13 mg MDA/kg at IM + CP 1.5% after oven-grilling; ABTS = 2.29 ± 0.05 mM/Trolox at Control + GP 0.5%;

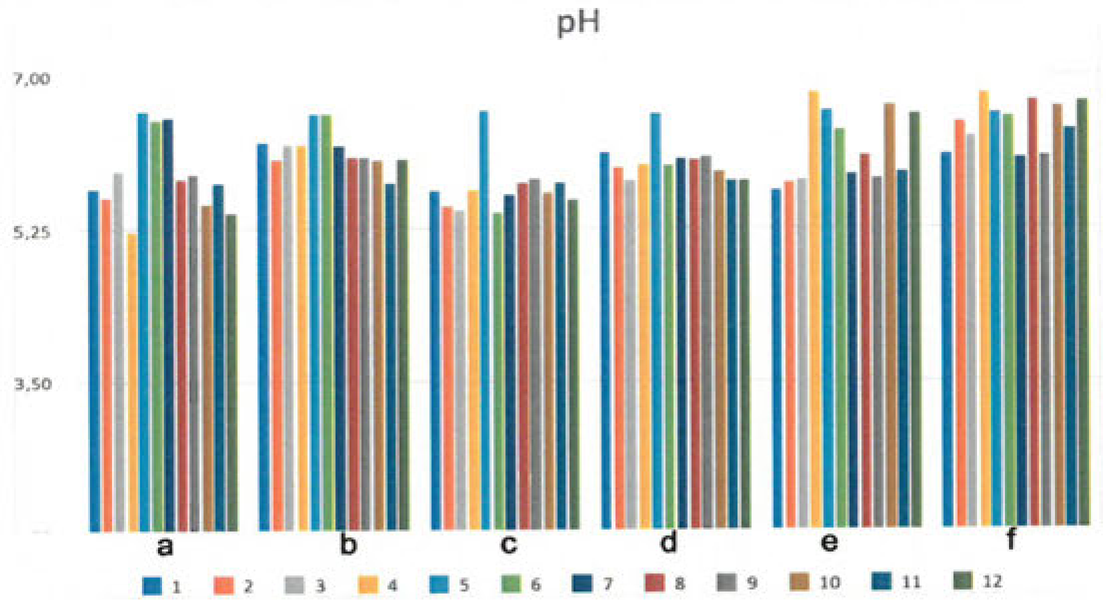

Figure 2. Changes in pH across the various marinated pork neck meat meat samples before and after oven-grilling. The different letters represent as follows: (a) = CP before oven-grill; (b) = CP after oven-grill; (c) = GP before oven-grill; (d) = GP after oven-grill; (e) = BS before oven-grill; (f) = BS after oven-grill; The number representations for different color shades are as follows: 1) control (antioxidant additive % = 0.0); 2) control (antioxidant additive % = 0.5); 3) control (antioxidant additive % = 1.0); 4) control (antioxidant additive % = 1.5); 5) AS (antioxidant additive % = 0.0); 6) AS (antioxidant additive % = 0.5); 7) AS (antioxidant additive % = 1.0); 8) AS (antioxidant additive % = 1.5); 9) IM (antioxidant additive % = 0.0); 10) IM (antioxidant additive % = 0.5); 11) IM (antioxidant additive % = 1.0); 12) IM (antioxidant additive % = 1.5). Cranberry pomace = CP; Grape pomace = GP; BS = Baikal Skullcap; African spice = AS; Industrial marinade/pickle = IM.

DPPH = 0.75 ± 0.00 mM/Trolox at AS + BS 1.0%; FRAP = .14 ± 0.01 mM/dm^3 at Control) values. The application of oven-grilling generally increased the pH, with a few exceptions, especially where either resemblances or decreases occurred. The pH range herein appears in contrast to data of Libera et al.[47] for dry-cured pork neck (pH ranges of 5.42 and 5.76). Olsson and Pickova[48] reported a well-fed and unstressed pig postmortem would have a pH typically fall from 7.2 to about 5.5, given by the biochemical and physical processes that help the conversion of (postmortem) muscle to meat. As shown in Figure 3, there seems to be more variations of pH by difference associated with those of CP, before BS and then GP marinade concentrations. Nonetheless, Siroli et al.[19] reported a reduced pH should favor the pork neck meat, which should provide it with a positive shelf potential, either to decrease the vulnerability to microbial proliferation, and/or facilitate the action of collagenases alongside other proteolytic enzymes associated with meat tenderization.

As fluctuations seemingly persisted with ABTS and DPPH values especially when AS and IM were incorporated, the FRAP values would appear lower at AS alone compared to control, but not so for with IM alone. Despite this, ABTS, DPPH, and FRAP seemingly decrease with increasing CP, GP, and BS concentrations (Figure 4a-c). Biologically active ingredients present in marinades are believed to have the capacity to quench the DPPH$^+$ radicals, which could depend on the muscle type[49] that prevail in the pork neck meat of this current study. Hypothetically, to quench DPPH$^+$ radical would entail slow (reaction) compounds that utilize more complex (reaction) mechanisms. Thus, the capacity of antioxidants to reduce/quench free radicals should help to extend the shelf-life of processed foods.[49] Moreover, the proteins/peptides could affect some antioxidant action in meat muscle, which might facilitate the chelating capacity of oxidative metals to probably scavenge some free radicals.[50]

The use of crushed seasonings/spices in meat processing could facilitate the release of polyphenols, which could become oxidized into electrophilic quinoae species. More so, the essence of using either CP, GP, or BS together with either AS or IM to make a herb mix herein, provides, not only adds flavor

Table 1. Changes in thiobarbituric acid reactive substance (TBARS) across the various marinated oven-grilled pork neck meat samples compared to control.

TBARS [mg malondialdehyde/kg]			Before oven-grilling	After oven-grilling
AS		control	10.55 ± 0.26^{n}	4.36 ± 0.12^{a}
	CP	0.5%	8.18 ± 0.26^{k}	11.00 ± 0.13^{n}
		1%	9.45 ± 0.26^{l}	8.18 ± 0.21^{jk}
		1.5%	13.82 ± 0.12^{o}	8.64 ± 0.13^{jklm}
	GP	0.5%	6.00 ± 0.22^{hi}	5.91 ± 0.13^{def}
		1%	6.09 ± 0.13^{hi}	14.55 ± 0.00^{p}
		1.5%	7.09 ± 0.00^{j}	6.09 ± 0.39^{efg}
	BS	0.5%	4.27 ± 0.13^{b}	5.55 ± 0.13^{cde}
		1%	4.82 ± 0.13^{cd}	6.18 ± 0.00^{fgh}
		1.5%	4.81 ± 0.13^{cd}	5.27 ± 0.26^{bc}
Control			8.45 ± 0.39^{k}	6.73 ± 0.00^{hi}
	CP	0.5%	6.36 ± 0.26^{i}	12.82 ± 0.13^{o}
		1%	10.00 ± 0.00^{m}	8.64 ± 0.13^{jklm}
		1.5%	14.64 ± 0.13^{p}	9.09 ± 0.26^{m}
	GP	0.5%	5.82 ± 0.00^{gh}	4.91 ± 0.00^{ab}
		1%	4.73 ± 0.26^{bc}	5.45 ± 0.00^{bcd}
		1.5%	5.45 ± 0.00^{fg}	8.91 ± 0.51^{lm}
	BS	0.5%	4.91 ± 0.26^{cde}	6.64 ± 1.16^{ghi}
		1%	5.27 ± 0.00^{def}	8.73 ± 0.00^{klm}
		1.5%	4.82 ± 0.13^{cd}	5.73 ± 0.13^{cdef}
IM			9.00 ± 0.13^{l}	8.36 ± 0.00^{jkl}
	CP	0.5%	18.36 ± 0.26^{r}	20.36 ± 0.26^{q}
		1%	16.91 ± 0.77^{q}	11.00 ± 0.13^{n}
		1.5%	17.27 ± 0.26^{q}	22.09 ± 0.13^{r}
	GP	0.5%	10.45 ± 0.13^{mn}	10.91 ± 0.00^{n}
		1%	2.55 ± 0.26^{a}	10.73 ± 0.00^{n}
		1.5%	4.82 ± 0.13^{cd}	7.09 ± 0.00^{i}
	BS	0.5%	6.09 ± 0.13^{hi}	8.09 ± 0.13^{jk}
		1%	7.36 ± 0.13^{j}	8.18 ± 0.26^{jk}
		1.5%	6.36 ± 0.26^{i}	8.09 ± 0.13^{j}

Results are expressed as mean ± standard deviation (SD). Results along the column with same lowercase letter(s) do not differ significantly (p > 0.05). African spice = AS; Industrial marinade/pickle = IM; CP = Cranberry pomace; GP = Grape pomace; BS = Baikal Skullcap.

additives, but also; antioxidant and phenolic components to help regulate protein oxidation.[51] Comparing Figures 2–4, and Table 1, without AS and IM, the ABTS and FRAP values of oven-grilled pork neck meat seemingly decrease with increasing concentrations of either CP, GP, and slightly much less so at BS (particularly for FRAP). However, there are also some instances where pH and DPPH fluctuated with decreases and increases, like at CP concentrations before oven-grilling occurring alongside changes in TBARS, but not so for those of either GP or BS. Further, Table 1 reveals that oven-grilling alone in some instances could significantly decrease ($p < .05$) the TBARS values as AS and IM were incorporated. Without AS and IM, however, the TBARS would significantly increase ($p < .05$) particularly with CP concentrations, but not so for GP and BS. It can be that the application of thermal processing (such as oven-grilling) disrupts the chemical structure especially the polysaccharides and other associated non-carbohydrate components of plant cell wall, which would allow for the onset of Maillard reaction.[49]

Changes in physical aspects

Physical aspects (specific to L*a*b* color scales, cooking weight loss, and textural cutting force) of different marinated oven-grilled pork neck meat were investigated (Figures 5–6, and Table 2). Across all samples, considering oven-grilling and antioxidant additives, L*a*b* color scales, cooking weight loss, and textural cutting force values found various ranges, from minimum (L*color = 32.1 ± 1.9 at AS +BS 1.5% before oven-grill; a*color = 2.43 ± 0.4 at IM +GP 1.5% after oven-grill; b* color = 4.3 ± 0.9 at Control CP 1.5% before oven-grill; cooking weight loss = ~ 9.82% at AS + CP/BS; textural cutting

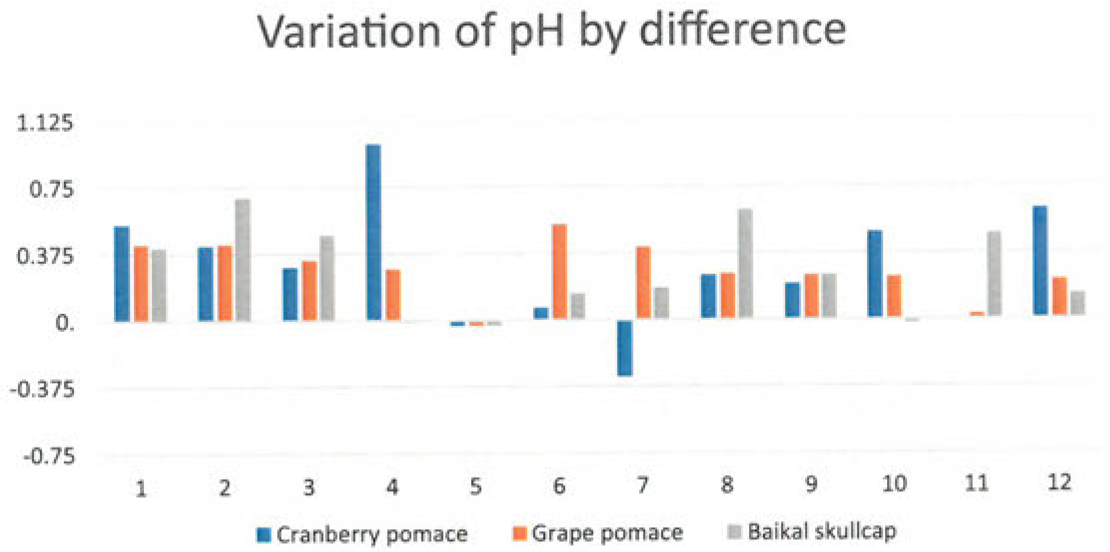

Figure 3. Variation of pH by difference across the various marinated oven-grilled pork neck meat samples compared to control. The number representations are as follows: 1) control (antioxidant additive % = 0.0); 2) control (antioxidant additive % = 0.5); 3) control (antioxidant additive % = 1.0); 4) control (antioxidant additive % = 1.5); 5) AS (antioxidant additive % = 0.0); 6) AS (antioxidant additive % = 0.5); 7) AS (antioxidant additive % = 1.0); 8) AS (antioxidant additive % = 1.5); 9) IM (antioxidant additive % = 0.0); 10) IM (antioxidant additive % = 0.5); 11) IM (antioxidant additive % = 1.0); 12) IM (antioxidant additive % = 1.5). African spice = AS; Industrial marinade/pickle = IM.

force = 22.4 ± 6.7 N at GP + IM 1.5%) to maximum (L*color = 52.5 ± 1.6 at BS/GP + IM 0.0% after oven-grill; a*color = 13.2 ± 0.2 at Control BS 1.5% before oven-grill; b* color = 21.5 ± 3.1 at IM+ BS 0.5% after oven-grill; cooking weight loss = ~ 38.29% at AS+ GP 1.5%; textural cutting force = 127.0 ± 1.0 N at CP + IM 1.5%) values. Results showed oven-grilling seemingly produced varying decreasing and increasing L*a*b* color values at some instances across the different marinated pork neck meat samples. Whereas the L* values would largely increase ($p < .05$) with few exceptions of slight decrease at BS control, the a* values would largely decrease ($p < .05$) with few exceptions at some CP, and GP samples. Moreover, increases in CP, GP, and BS concentrations may not always occur with L*a*b* color values. Besides b* color to influence the top layer/surface color of pork meat,[52] marinades that possess coloring compounds may equally influence some (pork) color attributes.[19] Any decrease in a* value may not necessarily depict an enhanced antioxidant effect, which would help to stabilize the color.[47] At slaughter, as muscle glycogen increases the resistance to stress-induced (glycogen) depletion, and coincides with obvious pH decreases, there would be an inevitable influence on the meat structure with high reflectance (paler color).[48]

Prior to and even after thermal processing, some moisture could still be held in the muscle tissues of the pork meat.[53] Particularly at the beginning of refrigerated storage, Siroli et al.[19] reported the marination process could reduce the cooking weight loss of pork meat. In this current work, the cooking weight loss fluctuated increasingly with decreases and increases at various instances, despite (increased) CP, GP, and BS concentrations and incorporating AS and IM. Moreover, the occurrence of cooking/drip loss would likely render the meat muscle (such as in pork neck) less acceptable, which could affect (product) color, weight, etc.[53,54] Interestingly, across the marinated oven-grilled pork neck meat, incorporating 0.5% CP seemingly increased the textural cutting force ($p < .05$), but would decrease when incorporating 0.5% GP, as well as 0.5% BS concentrations. Believed to negatively relate to muscle tenderness, any increase in cutting force would reflect the cracking phenomena potentially commencing within the muscle fibers.[54] For emphasis, the muscle tissue comprises connective aspect that involve myofibrillar proteins, which contribute to build up the meat tenderness.[55]

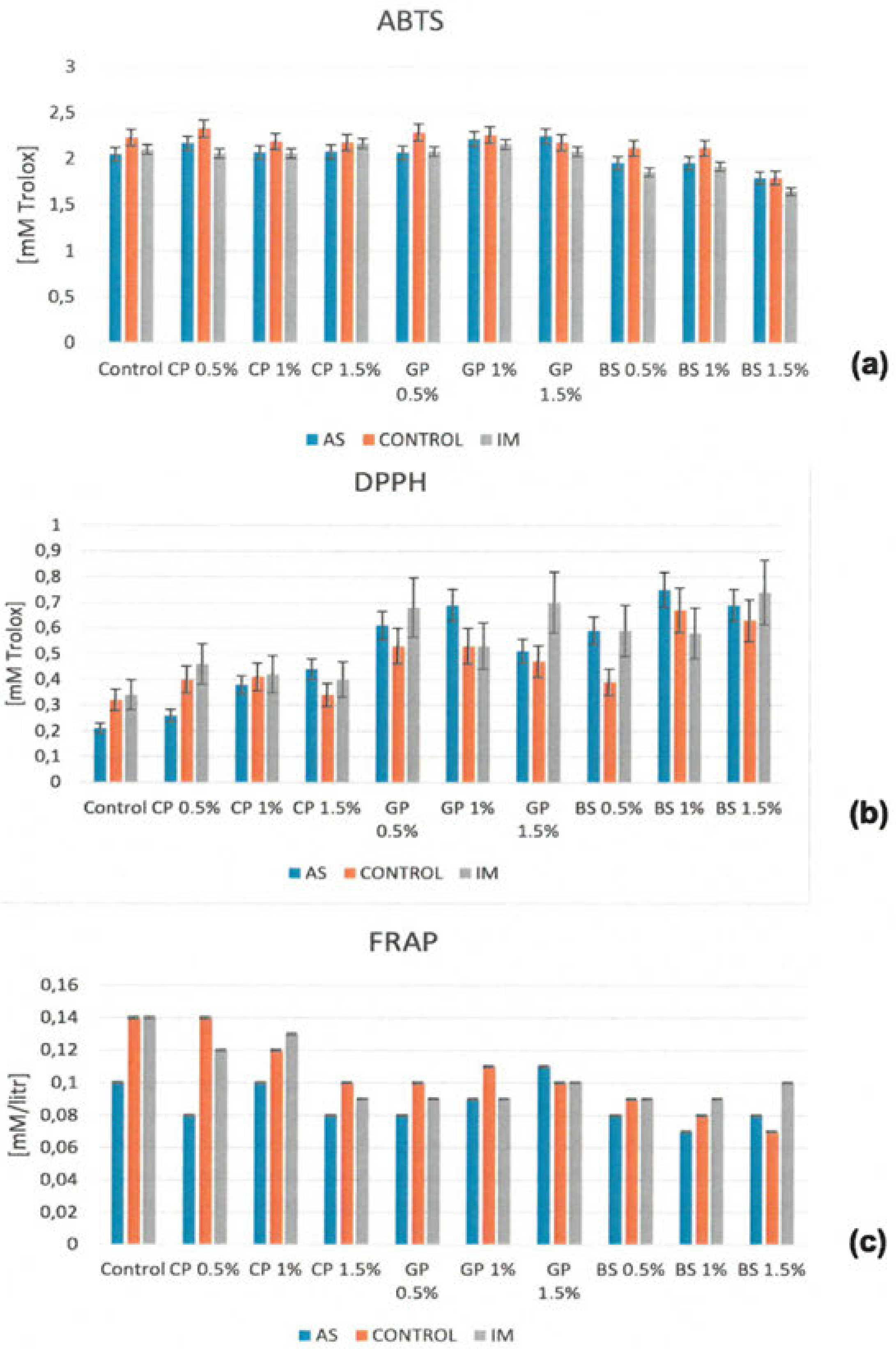

Figure 4. Changes in (a)ABTS (b) DPPH and (c)FRAP across the various marinated oven-grilled pork neck meat meat samples compared to control. Error bars show mean ± standard deviation (SD). ABTS = 2,2'-Azinobis-(3-ethylbenzthiazoline-6-sulfonate; DPPH = 1,1-diphenyl-2-pierylhydrazy (radical scavenging activity); FRAP = ferric reducing antioxidant power; Error bars shows mean values ± standard deviation (SD). African spice = AS; Industrial marinade/pickle = IM; CP = Cranberry pomace; GP = Grape pomace; BS = Baikal Skullcap.

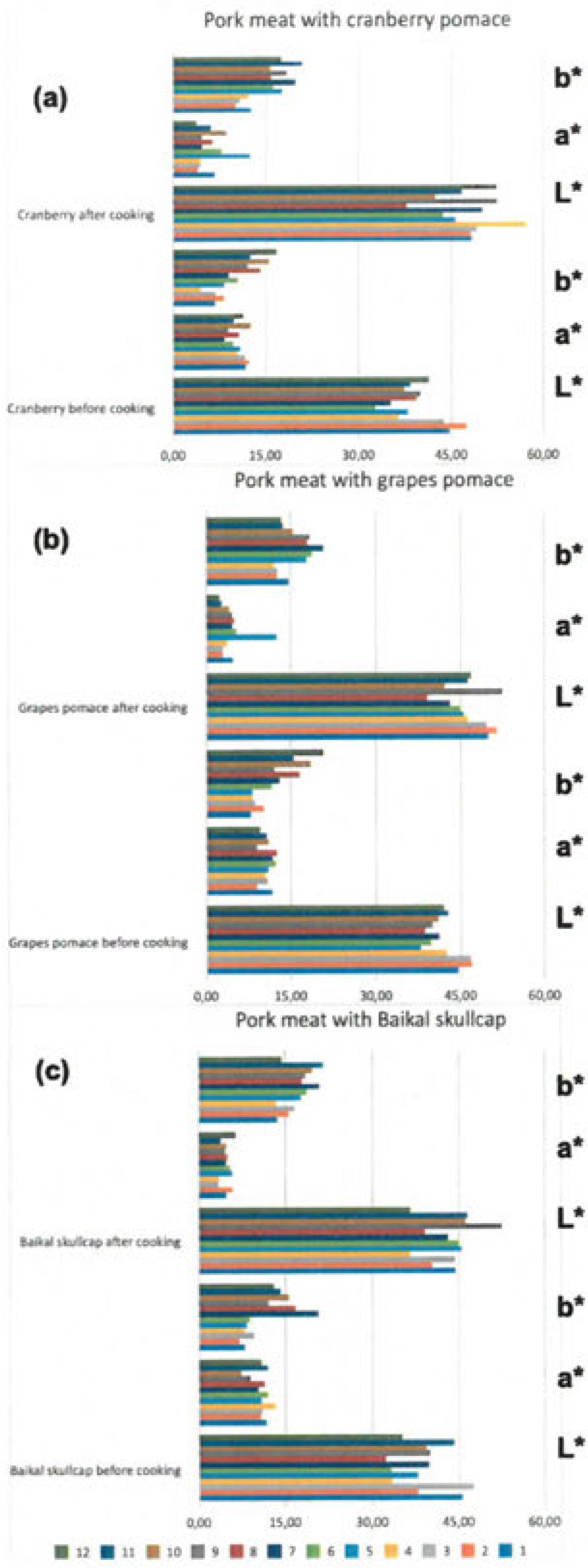

Figure 5. Changes in L*a*b* color of (a) cranberry pomace, (b) grape pomace, and (c) Baikal skullcap, across the various marinated oven-grilled pork neck meat samples. The number representations for different color shades are as follows: 1) control (antioxidant additive % = 0.0); 2) control (antioxidant additive % = 0.5); 3) control (antioxidant additive % = 1.0); 4) control (antioxidant additive % = 1.5); 5) AS (antioxidant additive % = 0.0); 6) AS (antioxidant additive % = 0.5); 7) AS (antioxidant additive % = 1.0); 8) AS (antioxidant additive % = 1.5); 9) IM (antioxidant additive % = 0.0); 10) IM (antioxidant additive % = 0.5); 11) IM (antioxidant additive % = 1.0); 12) IM (antioxidant additive % = 1.5). African spice = AS; Industrial marinade/pickle = IM.

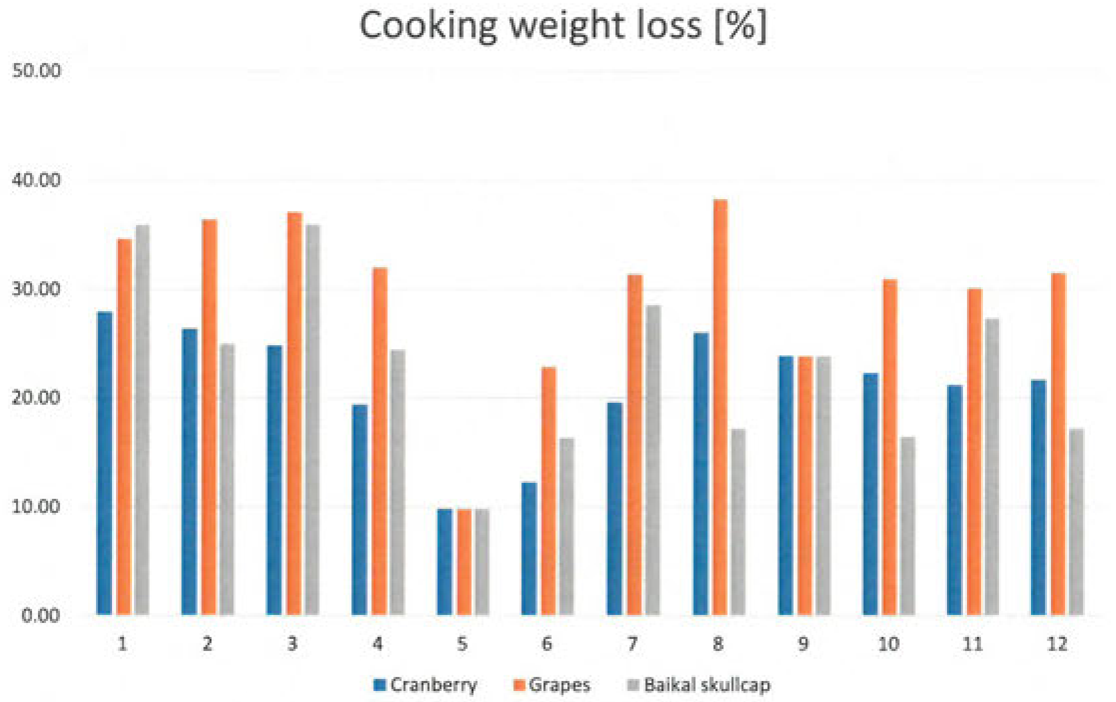

Figure 6. Changes in cooking weight loss (%) across the various marinated oven-grilled pork neck meat samples. The number representations for different color shades are as follows: 1) control (antioxidant additive % = 0.0); 2) control (antioxidant additive % = 0.5); 3) control (antioxidant additive % = 1.0); 4) control (antioxidant additive % = 1.5); 5) AS (antioxidant additive % = 0.0); 6) AS (antioxidant additive % = 0.5); 7) AS (antioxidant additive % = 1.0); 8) AS (antioxidant additive % = 1.5); 9) IM (antioxidant additive % = 0.0); 10) IM (antioxidant additive % = 0.5); 11) IM (antioxidant additive % = 1.0); 12) IM (antioxidant additive % = 1.5). African spice = AS; Industrial marinade/pickle = IM.

Changes in organoleptic aspects

The palatability of pork meat largely depends on the condition of the product being tested by the sensory panel. It also depends on the training the sensory panelists undertake, as well as the structure of the (sensory)test.[56] More so, a high score of sensory attributes for fatty taste, followed by meaty, and burnt taste as the least may reflect the direct heating nature of oven grill, which tends to mimic roasting.[52]

In this current work, the organoleptic aspects of various marinated oven-grilled pork neck meat were tested, specific to sensory appearance, flavor, taste, tenderness, and off-flavor, as well as textural chewiness, graininess, greasiness, gumminess, and hardness, respectively, shown in Tables 3 and 4. Across samples and considering oven-grilling and antioxidant additives, there were various range values in sensory appearance (from 3.00 ± 0.84 to 4.63 ± 0.92), flavor (from 3.33 ± 0.52 to 4.50 ± 0.93), taste (from 2.83 ± 0.82 to 4.56 ± 0.52), tenderness (from 2.63 ± 0.46 to 4.63 ± 0.92), with the exception of off-flavor (from 4.44 ± 0.79 to 5.00 ± 1.00), as well as textural chewiness (from 3.00 ± 1.41 to 6.33 ± 2.14), graininess (from 2.00 ± 1.28 to 3.88 ± 1.73), greasiness (from 2.67 ± 1.21 to 4.86 ± 3.72), gumminess (from 3.00 ± 2.48 to 6.00 ± 1.87), and hardness (from 3.13 ± 0.35 to 6.33 ± 0.41). Despite the many resemblances ($p > .05$), the sensory attributes showed fluctuations with increasing CP, GP, and BS concentrations, and as AS and IM were incorporated. Only the flavor seemingly decreases especially when incorporating AS. With respect to textural profile, in some marinated oven-grilled pork neck samples, the concentrations of CP and GP increase with hardness, and to some extent chewiness and gumminess, whereas in some others, the textural chewiness, gumminess, and hardness would increase especially when incorporating AS, slightly above those of IM.

The many data resemblances as well as fluctuations make establishing a specific trend across CP, GP, and BS concentrations of this current study especially for the organoleptic sensorial attributes seemingly quite challenging. Despite this, sensory evaluation remains among the most popular approach to evaluate the freshness of animal meat products as it provides useful information about product quality.[57] Connecting meat tenderness, for instance, with sensory often appear challenging because the sensation associated with consumption requires the understanding of various intricate stages, from initial ease to masticate, ease of grinding during chewing to achieve particles, to the mouthfeel of residue accumulated post-mastication.[55] Moreover, the combination of instrumental texture with sensory tenderness acceptability would corroborate shear force value, which may concur with unacceptable meat toughness.[58] The application of marinades, despite its influence on color of meat, would not negate the panelists' sensory evaluation.[19] Applicable to pork neck meat of this current work, the preservative potential of marinades would be better evidenced by refrigerated storage, which for instance is often demonstrated by differences in flavor, juiciness, and tenderness.[59]

Table 2. Changes in textural cutting force across the various marinated grilled pork neck meat samples compared to control.

Antioxidant additive	Marinade type	Percentage (%) of antioxidant additive	Pork cutting force [N]
	Control	0.0	42.8 ± 3.2^{abcd}
		0.5	58.2 ± 7.1^{de}
		1.0	51.8 ± 2.4^{bcde}
		1.5	54.5 ± 4.0^{cde}
CP	AS	0.0	58.0 ± 1.7^{de}
		0.5	58.4 ± 2.7^{de}
		1.0	55.4 ± 2.4^{cde}
		1.5	67.0 ± 3.3^{ef}
	IM	0.0	102.0 ± 0.0^{gh}
		0.5	85.0 ± 3.2^{fg}
		1.0	107.9 ± 3.9^{hi}
		1.5	127.0 ± 1.0^{i}
	Control	0.0	42.8 ± 3.2^{abcd}
		0.5	29.6 ± 1.0^{ab}
		1.0	34.9 ± 2.9^{abc}
		1.5	37.3 ± 1.2^{abcd}
GP	AS	0.0	67.1 ± 5.5^{ef}
		0.5	36.1 ± 7.7^{abcd}
		1.0	43.4 ± 1.3^{abcd}
		1.5	22.8 ± 9.4^{a}
	IM	0.0	28.7 ± 5.0^{ab}
		1.0	37.4 ± 1.2^{abcd}
		1.5	22.4 ± 6.7^{a}
	Control	0.0	36.3 ± 2.4^{abcd}
		0.5	31.4 ± 2.7^{ab}
		1.0	33.7 ± 1.2^{abc}
		1.5	24.3 ± 7.2^{a}
BS	AS	0.0	67.1 ± 5.5^{ef}
		0.5	26.9 ± 3.2^{a}
		1.0	44.9 ± 1.8^{abcde}
		1.5	31.4 ± 7.3^{ab}
	IM	0.0	28.7 ± 5.0^{ab}
		0.5	26.4 ± 1.4^{a}
		1.0	58.6 ± 9.3^{de}
		1.5	25.9 ± 3.3^{a}

Results are expressed as mean ± standard deviation (SD). Results followed by same lowercase letter(s) in the column of cutting force do not differ significantly ($p > 0.05$). African spice = AS; Industrial marinade/pickle = IM; CP = Cranberry pomace; GP = Grape pomace; BS = Baikal Skullcap.

Table 3. Sensory profile by way of flavour, appearance, tenderness, taste and off-flavour across the various marinated grilled pork neck meat samples compared to control.

			Flavour	Apperance	Tenderness	Taste	Off-flavor
Control	Control	0%	4.13 ± 0.83^{ab}	3.25 ± 0.92^{ab}	3.63 ± 1.39^{abcd}	3.88 ± 0.92^{cdef}	4.88 ± 0.83^{a}
	Grape pomace	0.5%	4.39 ± 0.00^{ab}	4.56 ± 0.53^{bc}	3.44 ± 0.53^{abcd}	3.39 ± 0.53^{bcdef}	4.33 ± 0.78^{a}
		1%	4.31 ± 0.70^{ab}	3.88 ± 1.03^{abc}	3.31 ± 1.13^{abcd}	3.56 ± 1.03^{bcdef}	4.50 ± 1.12^{a}
		1.5%	4.13 ± 0.80^{ab}	4.63 ± 0.92^{bc}	3.38 ± 0.74^{abcd}	3.44 ± 0.92^{bcdef}	4.88 ± 0.82^{a}
	Cranberry pomace	0.5%	4.00 ± 0.76^{ab}	3.94 ± 0.83^{abc}	3.88 ± 1.15^{abcd}	3.63 ± 0.83^{bcdef}	4.88 ± 0.92^{a}
		1%	4.44 ± 0.50^{ab}	3.81 ± 0.52^{abc}	4.63 ± 0.92^{d}	4.56 ± 0.52^{f}	5.00 ± 0.73^{a}
		1.5%	4.00 ± 0.76^{ab}	3.81 ± 0.76^{abc}	3.50 ± 1.00^{abcd}	4.00 ± 0.76^{cdef}	4.88 ± 1.07^{a}
	Scutellaria baicalensis	0.5%	3.67 ± 1.03^{a}	3.33 ± 1.02^{ab}	3.08 ± 1.03^{abc}	3.83 ± 1.02^{cdef}	5.00 ± 0.98^{a}
		1%	3.83 ± 0.75^{ab}	3.83 ± 0.52^{abc}	2.67 ± 0.75^{ab}	3.00 ± 0.52^{abcd}	4.83 ± 0.89^{a}
		1.5%	3.67 ± 0.82^{a}	3.83 ± 0.75^{abc}	2.83 ± 0.98^{abc}	3.00 ± 0.75^{abcd}	4.83 ± 0.63^{a}
African Spices	Control	0%	3.63 ± 0.74^{a}	3.75 ± 1.41^{abc}	2.63 ± 0.46^{ab}	3.19 ± 1.41^{abcde}	5.00 ± 1.00^{a}
	Grape pomace	0.5%	3.71 ± 0.76^{a}	3.71 ± 1.22^{abc}	2.79 ± 0.95^{ab}	3.07 ± 1.22^{abcde}	4.64 ± 0.61^{a}
		1%	3.94 ± 0.78^{ab}	3.81 ± 1.16^{abc}	3.25 ± 0.92^{abcd}	3.63 ± 1.16^{bcdef}	4.75 ± 0.79^{a}
		1.5%	3.81 ± 0.84^{ab}	3.75 ± 0.84^{abc}	$3{>}19\pm0.89^{abc}$	3.25 ± 0.84^{bcdef}	4.75 ± 0.53^{a}
	Cranberry pomace	0.5%	3.88 ± 0.83^{ab}	3.50 ± 1.36^{ab}	3.13 ± 0.93^{abc}	3.75 ± 1.36^{bcdef}	5.00 ± 0.89^{a}
		1%	3.44 ± 0.90^{a}	3.31 ± 0.71^{ab}	2.75 ± 1.28^{ab}	3.00 ± 0.71^{abcd}	4.88 ± 0.76^{a}
		1.5%	3.88 ± 0.83^{ab}	3.94 ± 0.93^{abc}	3.50 ± 0.68^{abcd}	3.94 ± 0.93^{cdef}	4.88 ± 0.42^{a}
	Scutellaria baicalensis	0.5%	3.40 ± 0.55^{a}	3.00 ± 0.84^{a}	3.80 ± 1.03^{abcd}	3.00 ± 1.37^{abcd}	4.60 ± 0.41^{a}
		1%	3.33 ± 0.52^{a}	3.33 ± 1.26^{ab}	3.00 ± 1.51^{abc}	3.33 ± 1.26^{bcdef}	5.00 ± 0.82^{a}
		1.5%	3.67 ± 0.82^{a}	4.17 ± 0.82^{abc}	2.67 ± 0.75^{ab}	2.83 ± 0.82^{abc}	5.00 ± 0.41^{a}
Industrial	Control	0%	4.50 ± 0.76^{ab}	4.44 ± 1.20^{abc}	3.50 ± 0.73^{abcd}	3.88 ± 1.20^{cdef}	4.75 ± 1.46^{a}
	Grape pomace	0.5%	4.50 ± 0.53^{ab}	4.38 ± 0.69^{abc}	3.38 ± 0.74^{abcd}	4.19 ± 0.69^{def}	5.00 ± 1.00^{a}
		1%	4.38 ± 0.74^{ab}	4.00 ± 0.89^{abc}	4.25 ± 0.93^{cd}	4.19 ± 0.89^{def}	4.88 ± 1.25^{a}
		1.5%	4.06 ± 0.78^{ab}	3.81 ± 0.56^{abc}	3.06 ± 0.84^{abc}	3.38 ± 0.56^{bcdef}	4.44 ± 0.79^{a}
	Cranberry pomace	0.5%	4.19 ± 0.84^{ab}	3.88 ± 1.18^{abc}	3.56 ± 1.25^{abcd}	4.13 ± 1.18^{cdef}	5.00 ± 0.35^{a}
		1%	4.50 ± 0.93^{ab}	3.94 ± 0.64^{abc}	3.88 ± 0.32^{abcd}	3.81 ± 0.64^{bcdef}	4.63 ± 0.92^{a}
		1.5%	4.38 ± 0.52^{ab}	3.94 ± 1.07^{abc}	4.00 ± 0.94^{bcd}	4.38 ± 1.07^{ef}	5.00 ± 0.92^{a}
	Scutellaria baicalensis	0.5%	4.17 ± 1.33^{ab}	3.75 ± 0.98^{abc}	2.83 ± 1.17^{abc}	3.50 ± 0.98^{bcdef}	4.83 ± 0.84^{a}
		1%	4.00 ± 0.89^{ab}	3.50 ± 1.05^{ab}	3.50 ± 1.38^{abcd}	3.50 ± 1.05^{bcdef}	4.83 ± 1.05^{a}
		1.5%	3.83 ± 0.75^{ab}	3.83 ± 0.98^{abc}	3.17 ± 0.75^{abc}	3.33 ± 0.98^{bcdef}	5.00 ± 0.82^{a}

Results are expressed as mean ± standard deviation (SD). Results along the column with same lowercase letter(s) do not differ significantly ($p > 0.05$).

Table 4. Textural profile by way of hardness, chewiness, gumminess, graininess, and greasiness across the various marinated grilled pork neck meat samples compared to control.

			Hardness	Chewiness	Guminess	Graininess	Greasiness
Control	Control	0%	4.67 ± 1.63^{abc}	4.67 ± 1.55^{ab}	4.50 ± 1.51^{ab}	3.17 ± 2.10^{ab}	3.50 ± 1.17^{ab}
	Grape pomace	0.5%	3.56 ± 1.00^{ab}	4.33 ± 1.46^{ab}	3.11 ± 1.69^{a}	2.56 ± 2.24^{ab}	2.78 ± 2.04^{ab}
		1%	4.00 ± 0.93^{ab}	4.75 ± 1.41^{ab}	4.38 ± 1.25^{ab}	3.13 ± 1.13^{ab}	4.00 ± 1.79^{ab}
		1.5%	5.13 ± 0.35^{abc}	5.25 ± 1.91^{abc}	3.75 ± 1.17^{ab}	2.88 ± 1.81^{ab}	3.13 ± 1.60^{ab}
	Cranberry pomace	0.5%	4.00 ± 0.35^{ab}	4.00 ± 1.60^{ab}	3.88 ± 1.67^{ab}	2.63 ± 1.41^{ab}	4.00 ± 2.62^{ab}
		1%	4.13 ± 0.25^{abc}	3.00 ± 1.41^{a}	3.13 ± 1.55^{a}	3.00 ± 1.60^{ab}	3.50 ± 2.56^{ab}
		1.5%	6.13 ± 0.35^{bcd}	5.38 ± 1.60^{abc}	4.75 ± 1.46^{ab}	3.75 ± 1.83^{ab}	3.88 ± 1.10^{ab}
	Scutellaria baicalensis	0.5%	4.17 ± 0.00^{abc}	4.17 ± 1.63^{abc}	3.50 ± 1.64^{ab}	2.33 ± 1.94^{ab}	2.92 ± 1.05^{ab}
		1%	6.33 ± 0.41^{bcd}	6.33 ± 2.14^{bc}	6.00 ± 1.87^{bc}	2.83 ± 1.75^{ab}	3.17 ± 1.74^{ab}
		1.5%	4.50 ± 0.41^{bcd}	4.83 ± 2.34^{ab}	5.00 ± 2.37^{ab}	2.33 ± 1.94^{ab}	3.00 ± 0.98^{ab}
African Spices	Control	0%	6.25 ± 0.46^{bcd}	5.50 ± 2.27^{abc}	5.63 ± 1.75^{ab}	3.25 ± 1.75^{ab}	4.50 ± 2.51^{ab}
	Grape pomace	0.5%	6.29 ± 0.94^{bcd}	5.29 ± 2.50^{abc}	4.86 ± 1.52^{ab}	2.29 ± 1.38^{ab}	4.86 ± 3.72^{ab}
		1%	5.38 ± 0.71^{abcd}	4.50 ± 1.93^{ab}	3.00 ± 2.48^{a}	2.75 ± 1.83^{ab}	3.13 ± 1.96^{ab}
		1.5%	5.00 ± 0.46^{abc}	6.00 ± 2.33^{abc}	4.00 ± 1.85^{ab}	3.00 ± 1.85^{ab}	4.00 ± 2.51^{ab}
	Cranberry pomace	0.5%	5.50 ± 0.25^{abcd}	4.38 ± 1.92^{ab}	4.00 ± 2.10^{ab}	3.13 ± 2.17^{ab}	4.00 ± 1.85^{ab}
		1%	5.63 ± 0.35^{abcd}	4.50 ± 1.93^{ab}	4.63 ± 1.51^{ab}	3.13 ± 1.81^{ab}	4.00 ± 2.33^{ab}
		1.5%	4.88 ± 0.35^{abc}	4.63 ± 2.50^{ab}	4.38 ± 2.67^{ab}	3.00 ± 1.31^{ab}	2.88 ± 1.46^{ab}
	Scutellaria baicalensis	0.5%	5.40 ± 0.82^{abcd}	5.00 ± 2.07^{ab}	4.60 ± 1.16^{ab}	2.60 ± 1.24^{ab}	4.00 ± 1.55^{ab}
		1%	6.00 ± 0.95^{abcd}	5.50 ± 2.07^{abc}	5.33 ± 2.32^{ab}	2.83 ± 1.64^{ab}	4.00 ± 1.51^{ab}
		1.5%	5.33 ± 0.57^{abcd}	5.00 ± 1.26^{ab}	4.33 ± 2.50^{ab}	3.00 ± 2.23^{ab}	2.83 ± 1.90^{ab}
Industrial	Grape pomace	0%	6.25 ± 0.46^{bcd}	$5,50 \pm 2.27^{abc}$	5.63 ± 1.75^{ab}	3.25 ± 1.75^{ab}	4.50 ± 2.51^{ab}
		0.5%	4.75 ± 0.00^{abc}	5.50 ± 1.28^{abc}	4.00 ± 1.51^{ab}	2.25 ± 1.73^{ab}	3.63 ± 1.55^{ab}
		1%	3.13 ± 0.35^{a}	4.25 ± 1.31^{ab}	3.38 ± 1.28^{ab}	2.00 ± 1.28^{a}	4.00 ± 2.27^{ab}
		1.5%	4.50 ± 1.05^{abc}	4.38 ± 2.25^{ab}	3.25 ± 1.85^{ab}	2.50 ± 1.07^{ab}	3.13 ± 2.73^{ab}
	Cranberry pomace	0.5%	5.63 ± 0.00^{abcd}	5.50 ± 1.77^{abc}	4.88 ± 2.20^{ab}	3.88 ± 1.73^{ab}	3.63 ± 2.50^{ab}
		1%	5.38 ± 0.74^{abcd}	5.38 ± 1.92^{abc}	4.50 ± 1.25^{ab}	3.38 ± 1.60^{ab}	4.63 ± 2.62^{ab}
		1.5%	5.63 ± 0.00^{abcd}	4.88 ± 1.73^{ab}	5.25 ± 1.31^{ab}	3.13 ± 1.55^{ab}	5.38 ± 2.07^{b}
	Scutellaria baicalensis	0.5%	4.00 ± 0.41^{ab}	5.33 ± 1.37^{abc}	4.00 ± 2.45^{ab}	2.67 ± 1.97^{ab}	3.67 ± 1.37^{ab}
		1%	4.50 ± 0.41^{abc}	4.50 ± 2.51^{ab}	3.83 ± 1.72^{ab}	2.67 ± 2.42^{ab}	3.00 ± 1.55^{ab}
		1.5%	5.50 ± 0.00^{abcd}	5.83 ± 2.04^{abc}	5.00 ± 2.45^{ab}	2.67 ± 1.97^{ab}	2.67 ± 1.21^{ab}

Results are expressed as mean ± standard deviation (SD). Results along the column with same lowercase letter(s) do not differ significantly ($p > 0.05$).

Conclusion

Various range values occurred across the quality attributes of the marinated oven-grilled pork neck meat samples. Decreases in ABTS and FRAP, with variations of pH by difference that seemingly associated with increasing concentrations of either CP, BS, and GP, would not always coincide with L*a*b* color trends. To establish a specific organoleptic sensory and texture trend across CP, GP, and BS proved challenging. Overall, the oven-grilling process promises to moderate the range values of key quality attributes of the different marinated pork neck meat of this current study. Considering the results, the direction of future work should be to evaluate the microbiological quality of the different marinated oven-grilled pork neck meat, in order to deduce the potential microbial entities that could be of interest. When such information is established, it would then be useful to submit this various marinated oven-grilled pork neck meat to different refrigerated storage/packaging conditions. This will help establish the preservative efficacy of marinades/marination variants as well as oven-grilling treatment.

Acknowledgments

Authors CORO, KL, SJ, and MK acknowledge financial support from Wroclaw University of Environmental and Life Sciences, Poland. Author RPFG acknowledges financial support from Polytechnic Institute of Viseu, Portugal.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was funded by, and its publication made open access thanks to Wrocław University of Environmental and Life Sciences, Wrocław-Poland.

ORCID

Charles Odilichukwu R Okpala http://orcid.org/0000-0003-4475-8887
Małgorzata Korzeniowska http://orcid.org/0000-0002-0300-0407

Authorship contribution

Conceptualization, CORO and MK; Data curation, HS, CORO, SJ, KL, and MK; Formal analysis, HS, CORO, SJ, KL, and MK; Funding acquisition, CORO, SJ, KL, and MK; Investigation, CORO, HS, SJ, KL; Methodology, CORO, HS, SJ, KL, MK; Project administration, MK; Software, HS, SJ, KL; Supervision, MK and RPFG; Validation, HS, SJ, KL, RPFG; Visualization, HS, SJ, KL, RPFG; Writing – original draft, CORO and MK; Writing – review & editing, CORO and RPFG. All authors reviewed and approved the final manuscript.

Data availability statement

The datasets generated during and/or analyzed can be made available upon reasonable request from the corresponding authors.

References

[1] McGlone, J. J.;. The Future of Pork Production in the World: Towards Sustainable, Welfare-Positive Systems. *Animals.* 2013, *3*(2), 401–415. DOI: 10.3390/ani3020401.

[2] FAO's Animal Production and Health Division: Meat & Meat Products. https://www.fao.org/agriculture/animal-production-and-health/en (Accessed 04 September 2022)

[3] Eurostat. (2017). Pork production up in the EU. Products Eurostat News, Published 19-09-2017. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20170919-1 (Accessed 28 December 2022)

[4] Cook, R. (2022). Ranking Of Countries That Produce The Most Pork (USDA), Beef2Live. https://beef2live.com/story-ranking-countries-produce-pork-usda-508-213044 Accessed 04 September 2022

[5] Szymańska, E. J.;. Functioning of the Supply Chain of Pork in Poland. *J. Agribus. Rural Dev.* 2015. DOI: 10.17306/JARD.2015.59.

[6] Florowski, T.; Pisula, A.; Słowński, M.; Orzechowska, B. Processing Suitability of Pork from Different Breeds Reared in Poland. *Acta Scientiarum Polonorum Technologia Alimentaria.* 2006, *5*(2), 55–64.

[7] BC Cook Articulation Committee. (2015). Meat Cutting and Processing in the Food Service Industry. Victoria, B. C.: BCcampus. https://opentextbc.ca/meatcutting

[8] Arnarson, A. (2015). Pork 101: Nutrition Facts and Health Effects, In: Authority Nutrition: An Evidence-Based Approach, https://web.archive.org/web/20150408004138/http://authoritynutrition.com/foods/pork (Accessed 05 September 2022)

[9] Calorie-Count. (2022). Calories in Pork, Fresh, Loin, Tenderloin: Separable Lean Only, Cooked, Roasted. https://web.archive.org/web/20070906122726/http://www.calorie-count.com/calories/item/10061.html (Accessed 04 September 2022)

[10] National Institutes for Health (NIH). (2022). Thiamin- Fact Sheets for Professionals, National Institutes for Health -office of Dietary Supplements, US Department of Health, and Human Services. https://ods.od.nih.gov/factsheets/Thiamin-HealthProfessional/#h3 (Accessed September 4, 2022)

[11] Whitbread, D. (2022). Top 10 Foods Highest in Thiamin (Vitamin B1), Powered by USDA Nutrition Data, https://myfooddata.com/articles/thiamin-b1-foods.php (Accessed 04 September 2022)

[12] Toldrá, F.; Flores, M. The Use of Muscle Enzymes as Predictors of Pork Meat Quality. *Food Chem.* 2000, *69*(4), 387–395. DOI: 10.1016/S0308-8146(00)00052-2.

[13] Moya, V. J.; Flores, M.; Aristoy, M. C.; Toldrá, F. Pork Meat Quality Affects Peptide and Amino Acid Profiles during the Ageing Process. *Meat Sci.* 2001, *58*(2), 197–206. DOI: 10.1016/S0309-1740(00)00152-2.

[14] Martini, S.; Cattivelli, A.; Conte, A.; Tagliazucchi, D. Black, Green, and Pink Pepper Affect Differently Lipid Oxidation during Cooking and in Vitro Digestion of Meat. *Food Chem.* 2021, *350*, 129246. DOI: 10.1016/j.foodchem.2021.129246.

[15] Cassens, R. G.;. Historical Perspectives and Current Aspects of Pork Meat Quality in the USA. *Food Chem.* 2000, *69*(4), 357–363. DOI: 10.1016/S0308-8146(00)00048-0.

[16] Cheok, C. Y.; Chin, N. L.; Yusof, Y. A.; Mustapa Kamal, S. M.; Sazili, A. Q. Effect of Marinating Temperatures on Physical Changes of Traditionally Marinated Beef Satay. *J. Food Process. Preserv.* 2011, *35*(4), 474–482. DOI: 10.1111/j.1745-4549.2010.00490.x.

[17] Istrati, D.; Simion Ciuciu, A. M.; Vizireanu, C.; Ionescu, A.; Carballo, J. Impact of Spices and Wine□Based Marinades on Tenderness, Fragmentation of Myofibrillar Proteins and Color Stability in Bovine *Biceps Femoris* Muscle. *J. Texture Stud.* 2015, *46*(6), 455–466. DOI: 10.1111/jtxs.12144.

[18] Sokołowicz, Z.; Augustyńska-Prejsnar, A.; Krawczyk, J.; Kačániová, M.; Kluz, M.; Hanus, P.; Topczewska, J. Technological and Sensory Quality and Microbiological Safety of RIR Chicken Breast Meat Marinated with Fermented Milk Products. *Animals.* 2021, *11*(11), 3282. DOI: 10.3390/ani11113282.

[19] Siroli, L.; Baldi, G.; Soglia, F.; Bukvicki, D.; Patrignani, F.; Petracci, M.; Lanciotti, R. Use of Essential Oils to Increase the Safety and the Quality of Marinated Pork Loin. *Foods.* 2020, *9*(8), 987. DOI: 10.3390/foods9080987.

[20] Zhang, H.; Wu, J.; Guo, X. Effects of Antimicrobial and Antioxidant Activities of Spice Extracts on Raw Chicken Meat Quality. *Food Sci. Human Wellness.* 2016, *5*(1), 39–48. DOI: 10.1016/j.fshw.2015.11.003.

[21] Shahidi, F.; Hossain, A. Bioactives in Spices, and Spice Oleoresins: Phytochemicals and Their Beneficial Effects in Food Preservation and Health Promotion. *J. Food Bioactives.* 2018, *3*, 8–75. DOI: 10.31665/JFB.2018.3149.

[22] Jalali, M.; Mahmoodi, M.; Moosavian, S. P.; Jalali, R.; Ferns, G.; Mosallanezhad, A.; … Mosallanezhad, Z. The Effects of Ginger Supplementation on Markers of Inflammatory and Oxidative Stress: A Systematic Review and Meta□analysis of Clinical Trials. *Phytotherapy Res.* 2020, *34*(8), 1723–1733. DOI: 10.1002/ptr.6638.

[23] Zhang, Y.; Henning, S. M.; Lee, R. P.; Huang, J.; Zerlin, A.; Li, Z.; Heber, D.; Turmeric and Black Pepper Spices Decrease Lipid Peroxidation in Meat Patties during Cooking. *Int. J. Food Sci. Nutr.* 2015, *663*, 260–265. DOI:10.3109/09637486.2014.1000837.

[24] Amber, K.; Badawy, N. A.; El-Sayd, A. E. N. A.; Morsy, W. A.; Hassan, A. M.; Dawood, M. A. Ginger Root Powder Enhanced the Growth Productivity, Digestibility, and Antioxidative Capacity to Cope with the Impacts of Heat Stress in Rabbits. *J. Thermal Biol.* 2021, *100*, 103075. DOI: 10.1016/j.jtherbio.2021.103075.

[25] Awuchi, C. G.; Okpala, C. O. R. Natural Nutraceuticals, Especially Functional Foods, Their Major Bioactive Components, Formulation, and Health Benefits for Disease prevention-An Overview. *J. Food Bioact.* 2022, *19*, 97–123. DOI: 10.31665/JFB.2022.18317.

[26] Richardson, P.; Ed. *Improving the Thermal Processing of Foods*; Woodhead Publishing Limited: Cambridge, England, 2004; pp 520.

[27] Viegas, O.; Amaro, L. F.; Ferreira, I. M.; Pinho, O. Inhibitory Effect of antioxidant-rich Marinades on the Formation of Heterocyclic Aromatic Amines in pan-fried Beef. *J. Agric. Food Chem.* 2012, *60*(24), 6235–6240. DOI: 10.1021/jf302227b.

[28] Okpala, C. O. R.; Juchniewicz, S.; Leicht, K.; Korzeniowska, M.; Guiné, R. P. Antioxidant, Organoleptic and Physicochemical Changes in Different Marinated Oven-Grilled Chicken Breast Meat. *Foods.* 2022, *11*(24), 3951. DOI: 10.3390/foods11243951.

[29] Schröder, M. J. A.;. *Food Quality and Consumer Value: Delivering Food that Satisfies.* Archived from the original on 11 June 2016.; Springer: Berlin, 2003; pp 150.

[30] Ježek, F.; Kameník, J.; Macharáčková, B.; Bogdanovičová, K.; Bednář, J. Cooking of Meat: Effect on Texture, Cooking Loss and Microbiological quality–a Review. *Acta Vet. Brno.* 2020, *88*(4), 487–496. DOI: 10.2754/avb201988040487.

[31] Farhadian, A.; Jinap, S.; Abas, F.; Sakar, Z. I. Determination of Polycyclic Aromatic Hydrocarbons in Grilled Meat. *Food Control.* 2010, *21*(5), 606–610. DOI: 10.1016/j.foodcont.2009.09.002.

[32] Kerth, C. R.; Blair□Kerth, L. K.; Jones, W. R. Warner□Bratzler Shear Force Repeatability in Beef *Longissimus* Steaks Cooked with a Convection Oven, Broiler, or Clam□shell Grill. *J. Food Sci.* 2003, *68*(2), 668–669. DOI: 10.1111/j.1365-2621.2003.tb05729.x.

[33] Khan, M. I.; Min, J. S.; Lee, S. O.; Yim, D. G.; Seol, K. H.; Lee, M.; Jo, C. Cooking, Storage, and Reheating Effect on the Formation of Cholesterol Oxidation Products in Processed Meat Products. *Lipids Health Dis.* 2015, *14*(1), 1–9. DOI: 10.1186/s12944-015-0091-5.

[34] Kim, E. J.; Lee, S.; Park, D. H.; Kim, H.; Choi, M. J. Physicochemical Properties of Pork Neck and Chicken Leg Meat under Various Freezing Temperatures in a Deep Freezer. *Food Sci. Anim. Resour.* 2020, *40*(3), 444. DOI: 10.5851/kosfa.2020.e24.

[35] Salmon, C. P.; Knize, M. G.; Felton, J. S. Effects of Marinating on Heterocyclic Amine Carcinogen Formation in Grilled Chicken. *Food Chem. Toxicol.* 1997, *35*(5), 433–441. DOI: 10.1016/S0278-6915(97)00020-3.

[36] Barido, F. H.; Lee, S. K. Effect of Detoxified *Rhus Verniciflua* Extract on Oxidative Stability and Quality Improvement of Raw Chicken Breast during Cold Storage. *J. Anim. Sci. Technol.* 2022, *64*(2), 380. DOI: 10.5187/jast.2022.e20.

[37] Luciano, G.; Moloney, A. P.; Priolo, A.; Rohrle, F. T.; Vasta, V.; Biondi, L.; Monahan, F. J. Vitamin E and Polyunsaturated Fatty Acids in Bovine Muscle and the Oxidative Stability of Beef from Cattle Receiving Grass or concentrate-based Rations. *J. Anim. Sci.* 2011, *89*, 3759–3768. DOI: 10.2527/jas.2010-3795.

[38] Bai, W. K.; Zhang, F. J.; He, T. J.; Su, P. W.; Ying, X. Z.; Zhang, L. L.; Wang, T. Dietary Probiotic *Bacillus Subtilis* Strain Fmbj Increases Antioxidant Capacity and Oxidative Stability of Chicken Breast Meat during Storage. *PLoS One*. 2016, *11*(12), e0167339. DOI: 10.1371/journal.pone.0167339.

[39] Lengkidworraphiphat, P.; Wongpoomchai, R.; Taya, S.; Jaturasitha, S. Effect of Genotypes on Macronutrients and Antioxidant Capacity of Chicken Breast Meat. *Asian-australas. J. Anim. Sci.* 2020, *33*(11), 1817. DOI: 10.5713/ajas.19.0736.

[40] Ali, M. D.; Kang, G. H.; Yang, H. S.; Jeong, J. Y.; Hwang, Y. H.; Park, G. B.; Joo, S. T. A Comparison of Meat Characteristics between Duck and Chicken Breast. *Asian-australas. J. Anim. Sci.* 2007, *20*(6), 1002–1006. DOI: 10.5713/ajas.2007.1002.

[41] Kopec, W.; Jamroz, D.; Wiliczkiewicz, A.; Biazik, E.; Pudlo, A.; Korzeniowska, M.; . . . Skiba, T. Antioxidative Characteristics of Chicken Breast Meat and Blood after Diet Supplementation with Carnosine, L-histidine, and β-alanine. *Antioxidants*. 2020, *9*(11), 1093. DOI: 10.3390/antiox9111093.

[42] Augustyńska-Prejsnar, A.; Ormian, M.; Sokołowicz, Z.; The Influence of Frozen Storage Duration and Thawing Methods on the Meat Quality of Broiler Chickens. *Apar Badaw Dydakt* 2017, 22.

[43] Augustyńska-Prejsnar, A.; Ormian, M.; Sokołowicz, Z. Physicochemical and Sensory Properties of Broiler Chicken Breast Meat Stored Frozen and Thawed Using Various Methods. *J. Food Qual.* 2018, 2018.

[44] Brambila, G. S.; Bowker, B. C.; Zhuang, H. Comparison of Sensory Texture Attributes of Broiler Breast Fillets with Different Degrees of White Striping. *Poultr. Sci.* 2016, *95*(10), 2472–2476. DOI: 10.3382/ps/pew165.

[45] Çakmakçı, S.; Topdaş, E. F.; Kalın, P.; Han, H.; Şekerci, P.; Köse, L. P.; Gülçin, İ. Antioxidant Capacity and Functionality of Oleaster (*Elaeagnus angustifolia* L.) Flour and Crust in a New Kind of Fruity Ice Cream. *Int. J. Food Sci. Technol.* 2015, *50*(2), 472–481. DOI: 10.1111/ijfs.12637.

[46] Civille, G. V.; Thomas Carr, B. *Sensory Evaluation Techniques*, 5th ed. CRC Press: Florida-USA, 2015.

[47] Libera, J.; Kononiuk, A.; Kęska, P.; Wójciak, K. Use of Grape Seed Extract as a Natural Antioxidant Additive in dry-cured Pork Neck Technology. *Biotechnol. Food Sci.* 2018, *82*, 2.

[48] Olsson, V.; Pickova, J. The Influence of Production Systems on Meat Quality, with Emphasis on Pork. *AMBIO: J. Hum. Environ.* 2005, *34*(4), 338–343. DOI: 10.1579/0044-7447-34.4.338.

[49] Moroney, N. C.; O'Grady, M. N.; Lordan, S.; Stanton, C.; Kerry, J. P. Seaweed Polysaccharides (Laminarin and Fucoidan) as Functional Ingredients in Pork Meat: An Evaluation of anti-oxidative Potential, Thermal Stability and Bioaccessibility. *Mar. Drugs*. 2015, *13*(4), 2447–2464. DOI: 10.3390/md13042447.

[50] Brychcy, E.; Król, Ż.; Kulig, D.; Jarmoluk, A. The Effect of Carrageenan and Gelatine Hydrosols Incorporated with Acidic Electrolysed Water on Surface Microbiota and Quality Changes on Pork Meat. *Int. J. Food Sci. Technol.* 2016, *51*(7), 1618–1629. DOI: 10.1111/ijfs.13132.

[51] Xiong, Y. L.;. Muscle Protein Oxidation and Functionality: A Global View of a once-neglected Phenomenon. *Meat Muscle Biol.* 2022, *5*(3), 14349. DOI: 10.22175/mmb.14349.

[52] Biller, E.; Kleniewska, M. The Composition of Volatile Compounds, Parameters of Colour and Sensory Quality Attributes of Roasted Pork Neck Shoulder Derived from Polish Meat. *Polish J. Appl. Sci.*2017, *2*(2), 59–65.

[53] Kerr, W. L.; Wang, X.; Choi, S. G. Physical and Sensory Characteristics of Low□fat Italian Sausage Prepared with Hydrated Oat. *J. Food Qual.* 2005, *28*(1), 62–77. DOI: 10.1111/j.1745-4557.2005.00010.x.

[54] Xia, X.; Kong, B.; Liu, J.; Diao, X.; Liu, Q. Influence of Different Thawing Methods on Physicochemical Changes and Protein Oxidation of Porcine Longissimus Muscle. *LWT Food Sci. Technol.* 2012, *46*(1), 280–286. DOI: 10.1016/j.lwt.2011.09.018.

[55] Migdał, W.; Różycki, M.; Mucha, A.; Tyra, M.; Natonek-Wiśniewska, M.; Walczycka, M.; Krępa-Stefanik, K. Meat Texture Profile and Cutting Strength Analyses of Pork Depending on Breed and Age. *Ann. Anim. Sci.* 2020, *20*(2), 677–692. DOI: 10.2478/aoas-2019-0085.

[56] Miller, R.; Prusa, K. *Sensory Evaluation of Pork*; National Pork Board. Pork Quality. American Meat Science Association, USA: Pork, 1998; pp 1–20.

[57] Smaoui, S.; Hlima, H. B.; Ghorbel, R. The Effect of Sodium Lactate and Lactic Acid Combinations on the Microbial, Sensory, and Chemical Attributes of Marinated Chicken Thigh. *Poult. Sci.* 2012, *91*(6), 1473–1481. DOI: 10.3382/ps.2011-01641.

[58] Schilling, M. W.; Schilling, J. K.; Claus, J. R.; Marriott, N. G.; Duncan, S. E.; Wang, H. Instrumental Texture Assessment and Consumer Acceptability of Cooked Broiler Breasts Evaluated Using a Geometrically uniform-shaped Sample. *J. Muscle Foods*. 2003, *14*, 11–23. DOI: 10.1111/j.1745-4573.2003.tb00342.x.

[59] Kim, Y. J.; Jin, S. K.; Park, W. Y.; Kim, B. W.; Joo, S. T.; Yang, H. S. The Effect of Garlic or Onion Marinade on the Lipid Oxidation and Meat Quality of Pork during Cold Storage. *J. Food Qual.* 2010, *33*, 171–185. DOI: 10.1111/j.1745-4557.2010.00333.x.

04 czerwca 2023 r

(miejscowość i data)

Charles Odilichukwu R. OKPALA...

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy ...... *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023a). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470.....* mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

04 June 2023..........

data i podpis

Wrocław 03.04.2023

mgr inż. Szymon Juchniewicz
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

3.04.2023 Juchniewicz Szymon

Wrocław 03.04.2023

mgr inż. Katarzyna Leicht
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

03.04.23, Katarzyna.... Leicht..

…MSc Hanna Skendrović….

imię i nazwisko

12 maja 2023 r

(miejscowość i data)

…University of Zagreb, Zagreb, Croatia…….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470.*… mój udział polegał na uczestniczył w eksperymentach (badanie, metodologia, walidacja/wizualizacja danych) tej pracy.

13.05.2023. Hanna Skendrović

……………………………………

data i podpis

dr hab Małgorzata Korzeniowska, prof. uczelni 03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470,* mój udział polegał na uczestnictwie w powstawaniu koncepcji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

…Prof Dr. hab. Raquel P.F. Guine…. 01 czerwca 2023 r

imię i nazwisko (miejscowość i data)

Polytechnic Institute of Viseu, Portugal….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Skendrović, H., Korzeniowska, M., & Guiné, R. P. F. (2023). Quality attributes of different marinated oven-grilled pork neck meat. International Journal of Food Properties, 26(1), 453-470….* mój udział współnadzorował prace projektowe, udzielał wglądu w metodologię, uczestniczył w walidacji/ wizualizacji danych oraz w rewizji projektu pracy.

15 May 2023

……………………………………

data i podpis

PeerJ

Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes

Charles Odilichukwu R. Okpala[1,2], Szymon Juchniewicz[2], Katarzyna Leicht[2], Małgorzata Korzeniowska[2] and Raquel P. F. Guiné[3]

[1] UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia, Athens, Georgia, United States
[2] Department of Functional Food Products Development, Faculty of Biotechnology and Food Sciences, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland
[3] Centre for Natural Resources, Environment and Society (CERNAS-IPV), Polytechnic Institute of Viseu, Viseu, Portugal

ABSTRACT

Understanding the impact that combined action of marination and oven grill processes would have on such meat products as beef entrecôte is crucial from both consumer appeal and product development standpoints. Therefore, different marinated oven-grilled beef entrecôte meat specifically evaluating resultant physicochemical and organoleptic attributes were studied. The beef entrecôte meat was provided by a reputable local bovine farm/slaughter at Wroclaw, Poland. Physicochemical attributes involved antioxidant (2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP)), (pH, thiobarbituric acid reactive substance (TBARS), cooking weight loss, $L^*a^*b^*$ color, and textural cutting force). Organoleptic attributes involved sensory (flavour, appearance, tenderness, taste) and texture (hardness, chewiness, gumminess, graininess, and greasiness) aspects. Different marination variants involved constituent 0.5%, 1%, and 1.5% quantities of cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS), subsequently incorporated either African spice (AS) or industrial marinade/pickle (IM). Results showed pH, ABTS, DPPH, FRAP, TBARS, $L^*a^*b^*$ color, cooking weight loss, and textural cutting force, sensory and textural profile with varying range values. Concentration increases of either CP, GP, and or BS may not always go along with ABTS, DPPH, and FRAP values, given the observed decreasing or increasing fluctuations. As oven-grilling either increased or decreased the TBARS values alongside some color and textural cutting force trends, pH variations by difference seemed more apparent at samples involving GP, before CP, and then BS. The organoleptic attributes obtained differences and resemblances from both sensory and textural profile standpoints. Overall, oven-grilling promises to moderate both physicochemical and organoleptic range values of different marinated beef entrecôte meat samples in this study.

Submitted 10 November 2022
Accepted 2 March 2023
Published 16 March 2023

Corresponding authors
Charles Odilichukwu R. Okpala, charlesokpala@gmail.com
Małgorzata Korzeniowska, malgorzata.korzeniowska@upwr.edu.pl

Academic editor
Pawel Urban

Additional Information and Declarations can be found on page 20

DOI 10.7717/peerj.15116

Subjects Food Science and Technology, Nutrition
Keywords Beef entrecôte, Marination, Herbs and spices, Product development, Thermal processing

How to cite this article Okpala COR, Juchniewicz S, Leicht K, Korzeniowska M, Guiné RPF. 2023. Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ 11:e15116 DOI 10.7717/peerj.15116

INTRODUCTION

The global meat production recorded about 67 million metric tonnes as of 2013, but seemingly less as of 2020 at about 60.57 million metric tonnes (*McGlone, 2013*; *Cook, 2022*; *FAO, 2022*, accessed September 2022). Notably, the EU as of 2016 was positioned as the third largest global beef producer by area that occupied about 11.5% (*SustainBeef, 2021*). Among the countries in the EU of notable interest, Poland in 2021 obtained a total national cattle population of 6.4 million by the head, which placed this country as the sixth (EU) beef producer (*Nieuwsbericht, 2022*). But despite this data, the level of (beef) consumption is still considered as below average (*Nieuwsbericht, 2022*). Among key factors that influence beef cattle (meat) quality in Poland include age, breed, diet, meat production and processing, as well as her accession to the EU in May 2004 (*Domaradzki et al., 2017*; *Żakowska-Biemans et al., 2017*). From the commercial/industrial perspective, the method by which beef is processed in Poland would follow this pathway: beef meat products > cutting plants > slaughterhouses > mechanically separated meat, and after slaughter, there would be intermediaries/outlets that direct the delivery/purchase (*Szymańska, 2015*).

The quality of beef meat products is very important to consumers, distributors, producers, processors, and slaughterers. Also, beef meat quality would reflect four pathways: healthiness (nutritional quality), satisfaction (organoleptic quality), security (hygienic quality), and serviceability (ease of use, ability to be processed, and prices) (*Listrat et al., 2016*). Besides being a great protein source for human consumption, beef meat comprises typical structural features like connective tissue, muscle fibers, and tendon, typically enriched with bioavailable iron, zinc, and selenium as well as vitamins A, B, and D (*Geletu et al., 2021*; *Open Textbooks, 2022*). At post-mortem, the accelerated glycolysis alongside the formation of lipid peroxidation products confronts beef meat, and facilitates quality deterioration (*Toldrá & Flores, 2000*; *Martini et al., 2021*). Moreover, overall beef meat value would associate with intrinsic and extrinsic cues, which consumers employ to explain their quality expectations (*Domaradzki et al., 2017*). When slaughtered, different beef product types do emerge largely dependent on the cut portions. When butchers cut into the bone-in rib-eyes particularly (with the bone) on each side, there would remain about six leftover boneless steaks potentially available from the beef meat. And this particularly happens between each bone-in rib-eye, which is how the entrecôte would emerge (*TasteAtlas, 2023*). Indeed, the making of a traditional entrecôte from the rib area of a given beef carcass certainly requires some level of specific skillset (*Beef2live, 2022*). Recent studies involving various quality attributes of beef carcass appear to investigate more on steak, loins, and others (*Clinquart et al., 2022*; *Berger et al., 2018*; *Santos et al., 2021*) much less the entrecôte.

The use of natural agents that possess preservative potentials continues to be of increasing research interest, which has been demonstrated by antioxidant and antimicrobial properties that help maintain meat quality, extend shelf-life and prevent economic loss (*Al-Dalali, Li & Xu, 2022*; *Istrati et al., 2011*). Among such natural preservative agents, marinades have been shown in recent years as increasingly applied to meat products (*Cheok et al., 2011*; *Istrati et al., 2011*; *Sokołowicz et al., 2021*). Dependent on the duration as well as technique of the marination process, the meat muscle can take up marinade constituents (*Siroli et al., 2020*). Typically requiring the immersion of meat products in a slurry/solution mix, the marination process would allow the incorporation of other edible seasonings that improve flavor development. More so, the ingredients employed in the marination process could include the likes of black/regular pepper, herbs/spices, ginger, cranberry pomace, Baikal skullcap, peanut, *etc.* (*Al-Dalali, Li & Xu, 2022*; *Cheok et al., 2011*; *Istrati et al., 2011*; *Shahidi & Hossain, 2018*; *Sokołowicz et al., 2021*; *Martini et al., 2021*; *Zhang, Wu & Guo, 2016*), some of which are enriched with phenols, and flavonoids (*Amber et al., 2021*), beneficial polyphenols (*Roopchand et al., 2013*), as well as antimicrobial capacities (*Teplá et al., 2013*).

To make beef edible, thermal processing of one form or another remains inevitable, which over the decades has advanced, from cook-chill, grilling, ohmic heating, laser-based packaging, *etc.* (*Richardson, 2004*; *Viegas et al., 2012*). Of increasing interest is grilling, which is among such thermal processes that involve temperatures above 150 °C transferred by conduction, and through direct/radiant dry heat (*Schröder, 2003*; *Ježek et al., 2020*). More so, the application of grilling of various types to meat products has been reported by several workers (*Farhadian et al., 2010*; *Kerth, Blair-Kerth & Jones, 2003*; *Khan et al., 2015*; *Muga, Marenya & Workneh, 2021*; *Gómez, Ibañez & Beriain, 2019*; *Vişan et al., 2021*). Whereas *Muga, Marenya & Workneh (2021)* performed modeling thin-layer drying kinetics of marinated beef submitted to infrared-assisted hot air processing, and *Gómez, Ibañez & Beriain (2019)* investigated the physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations, *Vişan et al. (2021)* studied the marination of Black Angus beef meat subjected to a grilling process. Other cooking methods applied to beef meat, which paved way for examination and prediction of other quality attributes (*Kondjoyan et al., 2014*; *Onopiuk et al., 2021*). Despite the published information currently available, relevant information to specific marinated oven-grilled beef entrecôte meat has not be found. Understanding the impact that combined action of marination and oven grill processes would have on such meat products as beef entrecôte is crucial from both consumer appeal and product development standpoints. To supplement existing information, this current work investigated different marinated oven-grilled beef entrecôte meat, specifically the evaluation of resultant physicochemical and organoleptic attributes. The beef entrecôte meat was provided by a reputable local bovine farm/slaughter retailer that supplies the Wroclaw's Lower Silesia region of Poland.

MATERIALS AND METHODS

Schematic overview of experimental program

The schematic overview of the experimental program, demonstrating the major stages, from the procurement of beef entrecôte meat samples, preparation of marinade variants, oven-grilling activity, to analytical measurements are shown in Fig. 1. To reiterate, this current work was directed to establish how oven-grilling affected different marinated beef entrecôte meat samples specific to their physicochemical (antioxidants, pH and lipid oxidation, cooking weight loss, $L^*a^*b^*$ color, and textural cutting force), as well as

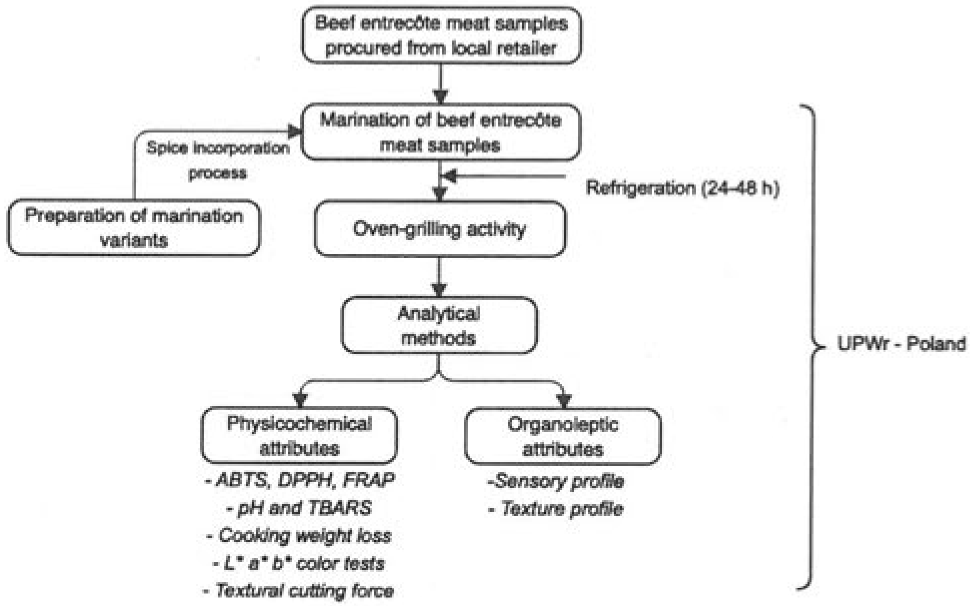

Figure 1 The schematic overview of the experimental program, showing the key stages, from the procurement of beef entrecôte meat samples, preparation of marinade variants, through oven-grilling activity, subsequently analytical measurements. ABTS, 2,2′-Azinobis-(3-ethylbenzthiazoline-6-sulphonate); DPPH, 2,2-diphenyl-1-picrylhydrazyl (radical scavenging activity); FRAP, ferric reducing antioxidant power; thiobarbituric acid reactive substance, TBARS; UPWr, Uniwersytet Przyrodniczy we Wrocławiu (Wroclaw University of Environmental and Life Sciences-Poland).

Full-size DOI: 10.7717/peerj.15116/fig-1

organoleptic (sensory = flavour, appearance, tenderness, taste and flavour; texture = hardness, chewiness, gumminess, graininess, and greasiness) attributes. Added that the beef entrecôte meat has been procured from a bovine farm in Poland, the different marination variants involved cranberry pomace, grape pomace, and Baikal skullcap that subsequently incorporated African spice, and Industrial marinade/pickle. Chemicals and reagents used at this work were of analytical grade standard. Additionally, all the laboratory experimentation adhered to the relevant guidelines set out by the Department of Functional Food Product Development, Wroclaw University of Environmental and Life Sciences-Poland.

Procurement, and preparation of beef entrecôte meat samples

Freshly processed beef entrecôte meat samples were procured from a reputable local bovine farm/slaughter retailer that supplies the Wroclaw's Lower Silesia region of Poland. The beef entrecote meat samples (~20 kg) placed in iced packed poly-boxes were transported to the Department of Functional Food Products Development, Wroclaw University of Environmental and Life Sciences., Poland. Upon arrival, the beef entrecôte meat samples were further cut into equivalent pieces of approximate thickness (9 cm × 9 cm × 3 cm). Afterwards, all samples were subject to cold room refrigeration (~2 °C) and ready for subsequent laboratory activities of marination and oven-grilling.

Preparation of marinades, and marination variants

The preparation of marinades followed the method described by *Okpala et al. (2023)*. This specifically involved Baikal Skullcap (BS), cranberry pomace (CP), as well as grape pomace (GP), that subsequently incorporated constant quantities of either African spice (AS) or Industrial marinade/pickle (IM) (each constituting 4 g), alongside salt (1.6 g).
For emphasis, on one hand, the African spice product (Fresh and Tasty Kebab Powder®) had been purchased from Fresh and Tasty Farms Ltd (Accra-North, Ghana), and its preparation followed the quality standards set by Food and Drugs Authority (FDA) Ghana. The label showed that this product comprised such ingredients as peanut, ginger, as well as black/regular pepper. More so, we utilized this AS product for the reason that it is increasingly being used at barbecues across Poland. On the other hand, the industrial marinade/pickle (Marinate do mięs) product had been purchased from Regis® Food Technology (Regis sp. z o.o., Kraków-Poland) and its preparation followed the quality standards set by the International Organization for Standardization (ISO), British Retail Consortium (BRC), and International Food Standard (IFS). The label showed that this product comprised such ingredients as marjoram, oregano, parsley, rosemary, and thyme. More so, we utilized this IM product for the reason that it already has an established reputation in Poland and other parts in the EU.

It is important to reiterate that the ground CP, GP, and BS served as antioxidant additives for this current study, using the method previously described (*Okpala et al., 2023*). The incremental concentrations of CP, GP, and BS made up 0.5%, 1%, and 1.5% by volume, which were calculated based on gram per 100 mL. Clean water served as liquid used to make up the marinade. Importantly, the marination variants were implemented as follows: (1) control where the antioxidant additive was not added (0.0%); (2) control with antioxidant additive of 0.5%; (3) control with antioxidant additive of 1.0%; (4) control with antioxidant additive of 1.5%; (5) AS incorporated with no antioxidant additive (0.0%); (6) AS incorporated with antioxidant additive of 0.5%; (7) AS incorporated with antioxidant additive of 1.0%; (8) AS incorporated with antioxidant additive of 1.5%; (9) IM incorporated with no antioxidant additive (0.0%); (10) IM incorporated with antioxidant additive of 0.5%; (11) IM incorporated with antioxidant additive of 1.0%; (12) IM incorporated with antioxidant additive of 1.5%. Following the method described by *Sokołowicz et al. (2021)* with modifications, the immersion method was adapted.
In particular, the amount of marinade was considered adequate to completely immerse the beef entrecôte meat samples, and this applied a 1:2 ratio of weight of meat (g) and marinade volume (mL). Additionally, plastic containers approved for contact with food was used to carry out the immersion process. The beef entrecôte meat samples were dipped sufficiently in the marinade variants for 24 h at 4 °C. Subsequently, after the immersion time had completed, the marinated beef entrecote samples were then allowed to drain (5 min), and placed in folded foiled packages ready for oven-grilling activity.

Oven-grilling procedure

The oven-grilling activity of marinated beef entrecôte meat samples employed an oven facility (CAMRY CR 6018; Serwis Centralny Camry, Warszawa, Poland). The oven-grilling operated with 2,200 W power, and set temperature of 180 °C. The beef entrecôte meat samples were placed evenly spaced in the oven-grill, which remained closed during the cooking process. Importantly, the opening of oven-grill was only when either to remove, or place new samples. Cooking time was kept constant at 5 min. During the cooking period, the internal temperature of the beef entrecote meat samples was routinely checked to ensure it was maintained roughly at about 75 °C. Upon completion of oven-grilling process, the emergent samples were allowed to cool briefly (15 min) at ambient temperature. Afterwards, emergent samples were then placed in foiled packages, submitted to refrigeration (4 °C), and then followed by analytical measurements.

Physicochemical measurements

Determination of antioxidant aspects

Prior to the antioxidant tests, the preparation of meat tissue supernatant followed the method described by *Bai et al. (2016)* with slight modifications. This required about a gram of beef meat entrecote tissue sample subjected to homogenization at 8,000 rpm for 10 s using 9 ml of 0.9% sodium chloride buffer, briefly placed on ice, subsequently centrifuged at 4,000 rpm for 15 min at 4 °C.

The 2,2′-azinobis(3-ethylbenzothiaziline-6-sulfonate) ($ABTS^+$) radical scavenging activity was performed using the method described by *Bai et al. (2016)* with slight modifications. The $ABTS^+$ has been produced by mixing 7 mM of $ABTS^+$ stock solution with 2.45 mM $K_2S_2O_8$, subsequently incubated in darkness at 25 °C for 12–16 h. Prior to using the reagent, the $ABTS^+$ solution was diluted with ethanol to an absorbance of 0.7000 ± 0.005 at 734 nm. From this, 10 µL of meat tissue supernatant were mixed with 990 µL of $ABTS^+$ solution and subsequently incubated at ambient temperature of ~25 °C for 6 min. The 990 µL of $ABTS^+$ solution mixed with 10 µL EtOH 70% served as the blank. Spectrophotometrically and against a blank, the absorbance was determined at 734 nm. The $ABTS^+$ radical scavenging activity has been expressed by mM Trolox.

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was performed using the method described by *Zhang et al. (2015)* with slight modifications. Specifically, there was an already prepared DPPH solution (0.3 mM) made with ethanol. Briefly, aliquots (20 µL) from meat tissue supernatant were mixed by vortex for 1 min with 200 µL 0.3 mM of ethanolic DPPH radical solution, then allowed to stand at ambient temperature (25 °C) for 30 min in the dark. Spectrophotometrically and against a blank, the absorbance was determined at 517 nm using a UV-Vis Spectrophotometer (GENESYS™ 180; Thermo Fisher Scientific Inc., Waltham, MA, USA), and DPPH radical scavenging activity expressed in mM Trolox.

The ferric reducing antioxidant power (FRAP) measurement was performed using the method described by *Lengkidworraphiphat et al. (2020)* with slight modifications. This required a mixture of FRAP solution containing 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ), 20 mM ferric chloride, together with 300 mM sodium acetate buffer (pH 3.6), at a ratio of 1:1:10 (v:v:v) added to the test specimen, and subsequently incubated for 30 min at 37 °C. The blank comprised 3 mL FRAP reagent mixed with 1 mL EtOH. The absorbance of resultant solution was read against a blank at 593 nm using a UV-Vis Spectrophotometer

(GENESYS™ 180; Thermo Fisher Scientific Inc., Waltham, MA, USA) and FRAP value expressed as mM/dm^3.

Determination of pH and lipid oxidation

The pH measurement was performed in triplicate using the method described by *Barido & Lee (2022)* with some modifications. This was specifically conducted before and after the oven-grilling activity. This required mixing a 5 g sample with 45 mL of distilled water in a homogenizer (PH91; SMT, Chiba, Japan) at 10,000 rpm, for 1 min using a portable pH meter (HI 99163; Hanna Instrument Company, Vöhringen, Germany) technically calibrated by buffer solutions (approximate pH 4.0, 7.0 and 9.0).

The thiobarbituric acid reactive substance (TBARS) measurement was performed in triplicate using the method described by *Luciano et al. (2011)* with slight modifications. This was specifically conducted before and after the oven-grilling activity. With the help of stomacher, the beef entrecôte meat samples (1.0 g) were homogenised with 10 mL of 10% trichloroacetic acid (TCA) for 1 min to precipitate proteins that are present. Subsequently, centrifugation was performed at 4,000× g (MPW-351R refrigerated; MPW Med. instruments Warszawa, Poland), and emergent mix was subject to filtration (Whatman #1 filter paper), from which 2 mL of supernatant was transferred to 2 mL of 0.06 M thiobarbituric acid. Placed in a water bath at 100 °C for 40 min, the reaction mixture was then cooled in ice-water bath (~2 min). The calibration curve was prepared using 1,1,3,3-tetra-ethoxypropane in TCA, as a standard solution. The samples were finally analysed, with absorbance was read against a blank at 532 nm using a UV-Vis Spectrophotometer (GENESYS™ 180; Thermo Fisher Scientific Inc., Waltham, MA, USA). According to the standard curve equation, TBARS values were expressed as mg of malondialdehyde (MDA) per kg of meat sample.

Determination of color and cooking weight loss

The color measurements were determined using the method described by *Kopec et al. (2020)* with slight modifications. This was specifically conducted before and after oven-grilling by way of CIE $L^*a^*b^*$ scale (L^* = darkness; a^* = redness/greenness; and b^* = yellowness/blueness) using a Minolta CR-40 reflection colorimeter (Konica Minolta Sensing Europe B.V., Nieuwegein, Netherlands). Three individual measurements were taken on different areas on the beef entrecôte meat surface, and the readings display results *via* the CIE $L^*a^*b^*$ colorimetric system were recorded.

The cooking weight loss measurements were determined using the method described by *Ali et al. (2007)* with slight modifications. Specifically, the samples have been weighed prior to and after oven-grilling. The cooking weight loss depicted cooked sample (B) weight as a percentage of precooked sample (A) weight as shown by the equation below:

$$\text{Cooking loss (\%)} = [(A - B)/(A)] \times 100 \tag{1}$$

Determination of textural cutting force

The textural cutting force measurement was performed using the method described by *Augustyńska-Prejsnar, Ormian & Sokołowicz (2017)* with slight modifications. The specific aim was to measure the force required to cut a piece of beef entrecôte meat. The facility employed to measure cutting force (Fmax) was the Zwick/Roell machine (Zwick GmbH & Co. KG, Ulm, Germany), already equipped with Warner-Bratzler V-blade knife, which moved at a head speed of 100 mm/min and an initial force of 0.2 N. The portions of beef entrecôte meat samples were estimated cross-sectional diameter of 100 mm^2 and 50 mm length.

Organoleptic measurements

Organoleptic measurements of beef entrecôte meat samples comprised sensorial analysis slightly modified from *Augustyńska-Prejsnar, Ormian & Sokołowicz (2018)*, and textural profiling slightly modified from *Brambila, Bowker & Zhuang (2016)*. Sensory panelists constituted ten (10) staff and graduate students of the Department of Functional Food Products Development, Wrocław University of Environmental and Life Sciences (Poland), who were already familiar with the evaluation criteria set out to differentiate between the levels of the beef entrecôte meat's flavor, appearance, tenderness, taste, and off-flavor specific to the sensorial profiling, as well as hardness, chewiness, gumminess, and graininess specific to the textural profiling. Importantly, the verbal consent taken prior to the sensory evaluation. Additionally, the panelists' participation was voluntary, and no names/gender was reported to ensure privacy. The panelists performed the organoleptic evaluation in a well-ventilated and distraction-free environment of neutral color, and with adequate lighting. The organoleptic assessment involved the evenly cut samples already cooled to 20 ± 2 °C placed in coded white plastic plates before each panelist. Importantly, warm water was made available to each panelist to cleanse taste palates between samples. This was conducted to ensure the previous evaluation did not affect the (taste of the) new one, consistent with the work of *Çakmakçı et al. (2015)*. The coded samples were evaluated using five-point scale (one point being the lowest score and five points being the highest) for the sensory aspects, and using 0 to 15 intensity scale for texture profile, modified from the description given by *Civille & Thomas Carr (2015)*.

Statistical analysis

The data, independently generated from different samples and based on a minimum of two determinations unless stated otherwise, were submitted to analysis of variance (ANOVA). Statistical significance was set at $p < 0.05$ (95% confidence level). The mean differences were resolved *post-hoc* by way of Turkey's test. Statistica 13.0 software (StatSoft GmbH, Hamburg, Germany) was used to run the data.

RESULTS AND DISCUSSION

Changes in antioxidant aspects

Notwithstanding that combination of herbs and spices makes marination to produce a promising antioxidant resource, different processing methods would alter its efficacy (*Thomas et al., 2010*; *Viegas et al., 2012*). This circumstance would be particularly applicable from the point when the marinated product has just been prepared, and when it is potentially ready for consumption. In this current work, the changes in ABTS, DPPH,

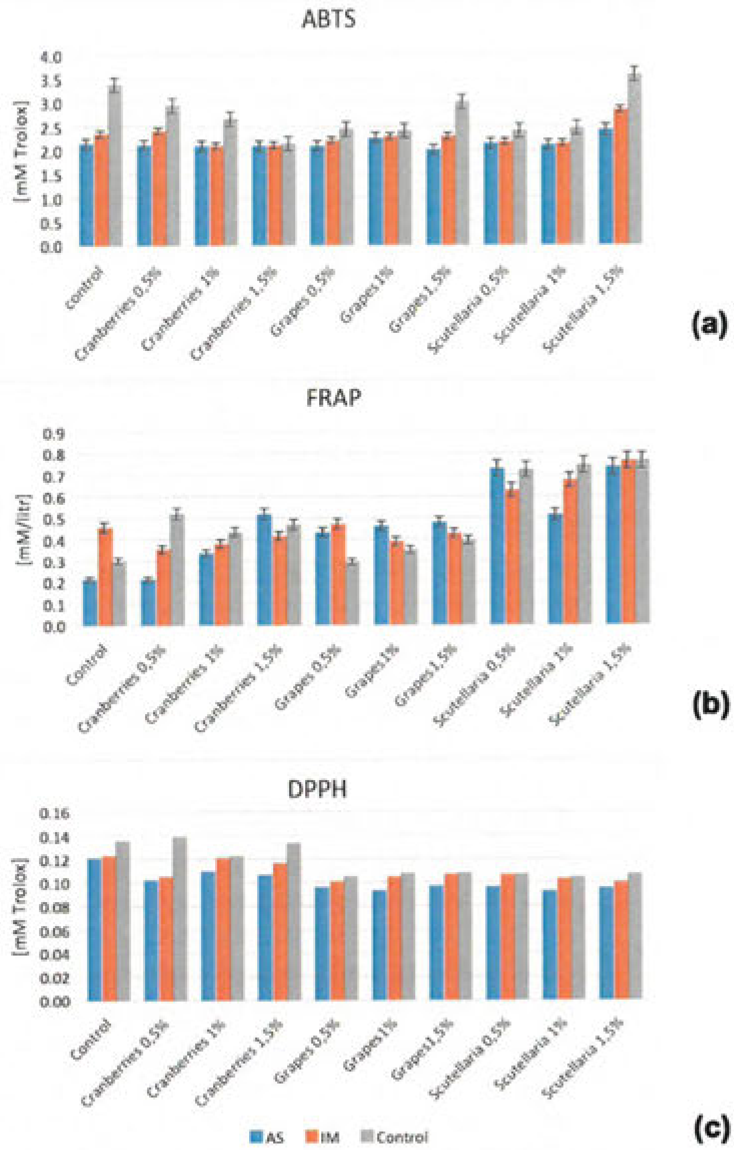

Figure 2 Changes in ABTS (A), FRAP (B), and DPPH (C) across the various marinated oven-grilled beef entrecôte meat samples compared to control. ABTS, 2,2′-Azinobis-(3-ethylbenzthiazoline-6-sulphonate; DPPH, 2,2-diphenyl-1-picrylhydrazyl (radical scavenging activity); FRAP, ferric reducing antioxidant power; Error bars shows mean values ± standard deviation (SD). African spice, AS; Industrial marinade/pickle, IM; BS, Baikal Skullcap. Results are expressed as mean ± standard deviation (SD).
Full-size DOI: 10.7717/peerj.15116/fig-2

and FRAP values of various marinated oven-grilled beef entrecôte meat samples compared to control can be seen in Fig. 2. Across CP, GP and BS incorporating either AS or IM, different ABTS, DPPH, and FRAP ranges (for ABTS: from 2.01 ± 0.14 mM/Trolox at IM+GP 1.5% to 3.58 ± 1.89 mM/Trolox at control +BS 1.5%; for DPPH: from 0.09 ± 0.00 mM/Trolox at either AS +BS 1% or control +GP 1% to 0.14 ± 0.00 mM/Trolox at either control or IM+CP 0.5%; for FRAP: from 0.21 ± 0.01 mM/lit at control + CP 0.5% to 0.76 ± 0.00 mM/lit at either AS+BS 1.5% or IM+BS 1.5%) were found. Whereas the control samples obtained a closer DPPH range (~0.12 to 0.14 mM/Trolox), those of marinated oven-grilled beef entrecote meat samples obtained wider ranged ABTS (~2.14 to ~3.38 mM/Trolox) and FRAP (~0.21 to ~0.46 mM/lit).

Figure 2 also depicts that ABTS, DPPH and FRAP values of various marinated oven-grilled beef entrecôte meat samples specific to increasing CP, GP, and BS concentrations seems comparable with those that incorporated either AS or IM. Besides, the increasing CP, GP and or BS concentrations may not always go along with ABTS, DPPH and FRAP values given the observed decreasing or increasing fluctuations. Emphasizing the increasing CP, GP and or BS concentrations incorporating either AS or IM likens to a herb mix as strengthening the antioxidant efficacy of the marinade medium (*Thomas et al., 2010*; *Viegas et al., 2012*; *Zhang et al., 2015*), the heat temperatures above 120 °C resembling (oven) grilling should be capable of decreasing the antioxidant activity (*Barido & Lee, 2022*). It is important to understand that thermal processing like oven-grilling could open up the plant cell wall components and make them to become more sensitive so as to allow the progress of Maillard reaction (*Moroney et al., 2015*). Capably, the amino acids, essential oils, antioxidants, flavones, phenylethanoids, as well as sterols that are available in such herbs like BS and GP herein should scavenge, for instance, the DPPH radicals, which would help to prevent the progress of rancidity (*Kim et al., 2012*; *Lee et al., 2014*; *Sáyago-Ayerdi, Brenes & Goñi, 2009*).

Changes in pH and TBARS

Applicable to beef meat quality, the changes in pH has for long been understood to associate with lower quantities of expressed juice, reflectance values, and cooking losses (*Purchas, 1990*). Besides pH considered as indicative of the acid concentration present, the use of marinades could eventually influence the physicochemical properties of the meat muscle (*Oreskovich et al., 1992*). In this current work, the changes in pH and TBARS values of the various marinated oven-grilled beef entrecôte compared to control are respectively shown in Figs. 3 and 4, as well as Table 1. Both pH and TBARS data obtained varying values. Specifically, the pH ranged from a minimum of ~5.38 at control GP before oven-grill, to a maximum of ~6.08 at control GP after oven-grill, whereas the TBARS ranged from a minimum of ~9.38 mg MDA/kg at AS+GP 0.5% to a maximum of ~26.36 mg MDA/kg at AS +GP 1%, the latter which resembled ($p > 0.05$) that of AS +GP 0.5% (~26.27 mg MDA/kg). Further, the oven-grilling seemed to either increase or decrease the TBARS values of some marinated beef entrecôte meat samples. For instance, oven-grilling appeared to noticeably reduce ($p < 0.05$) the TBARS of control (from ~17.18 to ~16.91 mg MDA/kg), in contrast to the increase when AS (from ~11.73 to 20.45 mg MDA/kg) and IM (from ~14.09 to ~24.91 mg MDA/kg) were incorporated. The detected pH and TBARS differences, which came from the application of either after oven-grilling and or together with marination variants, would most likely have shelf-life implications.

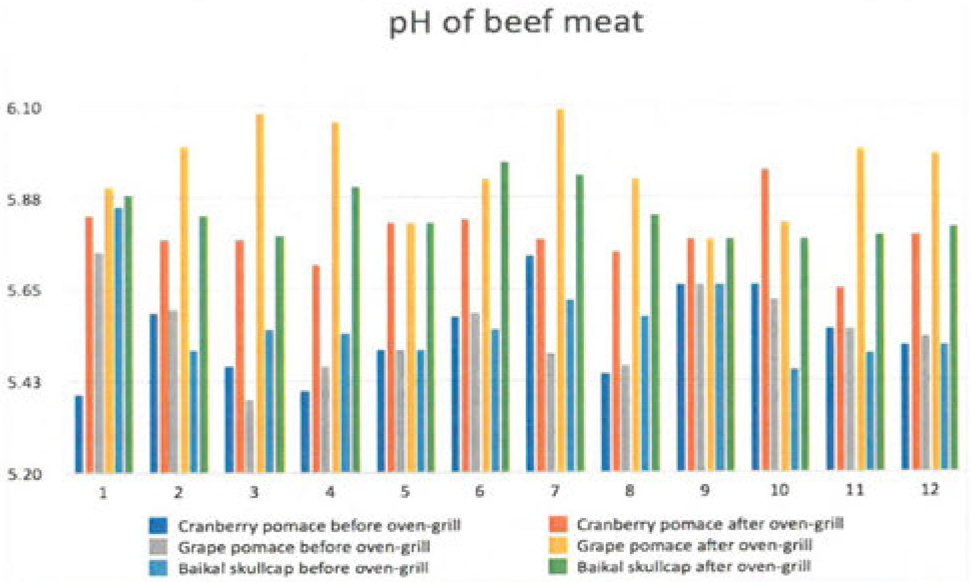

Figure 3 Changes in pH across the various marinated beef entrecôte meat samples before and after oven-grilling. The number representations for different colour shades are as follows: (1) control (antioxidant additive %= 0.0); (2) control (antioxidant additive %= 0.5); (3) control (antioxidant additive %= 1.0); (4) control (antioxidant additive %= 1.5); (5) AS (antioxidant additive %= 0.0); (6) AS (antioxidant additive %= 0.5); (7) AS (antioxidant additive %= 1.0); (8) AS (antioxidant additive %= 1.5); (9) IM (antioxidant additive %= 0.0); (10) IM (antioxidant additive %= 0.5); (11) IM (antioxidant additive %= 1.0); (12) IM (antioxidant additive %= 1.5). African spice, AS; Industrial marinade/pickle, IM; The antioxidant additives include cranberry pomace (CP), grape pomace (GP), and Baikal skullcap (BS).

Full-size DOI: 10.7717/peerj.15116/fig-3

Figure 4 shows variation of pH by difference appears more at different marinated oven-grilled beef entrecote samples especially of GP, before CP, and then BS marination variants. Despite this, the application of oven-grill seemed to generally increase the pH regardless of marination variants. Knowing that pH value reflects the quality of beef meat and its suitability for various processing methods (*Korkeala et al., 1986*), to keep it reduced promises a positive shelf potential, which should avert off-odor believed to be facilitated by collagenases and other proteolytic enzymes associated with meat tenderisation (*Siroli et al., 2020*). To employ either increasing concentrations of CP, GP, or BS together with either AS or IM that builds up an herb mix should help to regulate the protein oxidation within the meat muscle (*Xiong, 2022*). Moreover, higher temperatures that come from oven-grilling should facilitate the release of oxygen, heme, and iron in meat products like beef. This situation might have made the marinated beef entrecôte meat of this current study to appear susceptible to lipid oxidation. If this situation were to progress, however, it would be demonstrated by the induced free radical production followed by undesirable off-odors/flavors (*Amaral, Silva & Lannes, 2018*). Largely applicable to beef carcasses, the functionality of muscles would corroborate the proportion of either slow-twitch oxidative or fast-twitch glycolytic pathways (*Pereira et al., 2017*).

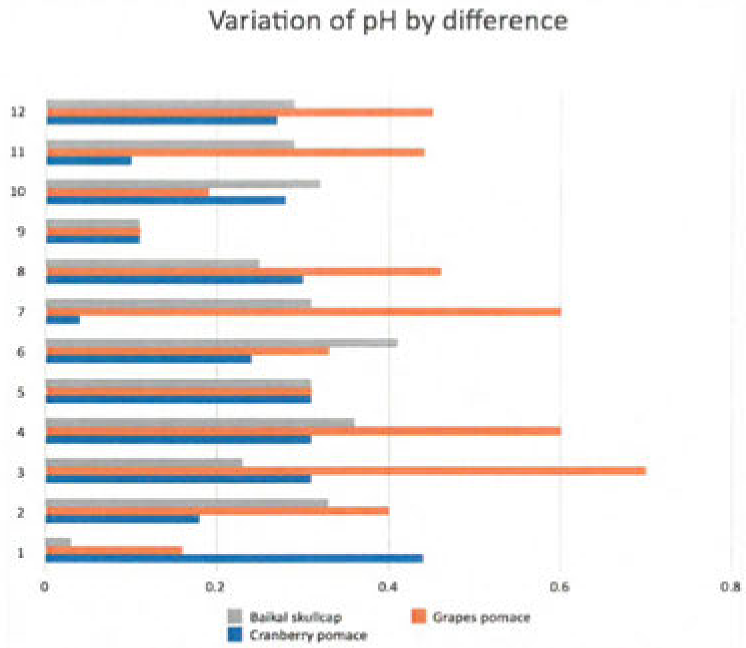

Figure 4 Variation of pH by difference across the various marinated oven-grilled beef entrecôte meat samples compared to control. The number representations are as follows: (1) control (antioxidant additive %= 0.0); (2) control (antioxidant additive %= 0.5); (3) control (antioxidant additive %= 1.0); (4) control (antioxidant additive %= 1.5); (5) AS (antioxidant additive %= 0.0); (6) AS (antioxidant additive %= 0.5); (7) AS (antioxidant additive %= 1.0); (8) AS (antioxidant additive %= 1.5); (9) IM (antioxidant additive %= 0.0); (10) IM (antioxidant additive %= 0.5); (11) IM (antioxidant additive %= 1.0); (12) IM (antioxidant additive %= 1.5). African spice, AS; Industrial marinade/pickle, IM; The antioxidant additives include cranberry pomace, grape pomace, and Baikal skullcap.

Full-size DOI: 10.7717/peerj.15116/fig-4

Table 1 Changes in thiobarbituric acid reactive substance (TBARS) across the various marinated oven-grilled beef entrecôte meat samples compared to control.

TBARS (mg malondialdehyde/kg)			Before oven-grill	After oven-grill
AS	Control		$11.73^{a} \pm 3.73$	$20.45^{abc} \pm 1.16$
	CP	0.5%	$12.91^{a} \pm 3.99$	$17.18^{abc} \pm 4.63$
		1%	$23.64^{a} \pm 4.11$	$22.91^{abc} \pm 3.73$
		1.5%	$24.00^{a} \pm 18.51$	$23.45^{abc} \pm 9.26$
	GP	0.5%	$9.36^{a} \pm 18.00$	$26.27^{bc} \pm 9.51$
		1%	$9.73^{a} \pm 0.13$	$26.36^{c} \pm 3.21$
		1.5%	$23.45^{a} \pm 0.39$	$19.82^{abc} \pm 2.57$
	BS	0.5%	$17.27^{a} \pm 14.14$	$16.18^{abc} \pm 3.86$
		1%	$17.55^{a} \pm 6.94$	$16.73^{abc} \pm 2.31$
		1.5%	$11.64^{a} \pm 6.81$	$13.45^{abc} \pm 1.80$

Table 1 (continued)

TBARS (mg malondialdehyde/kg)			Before oven-grill	After oven-grill
Control	Control		$17.18^{a} \pm 3.21$	$16.91^{abc} \pm 5.91$
	CP	0.5%	$16.73^{a} \pm 4.37$	$19.64^{abc} \pm 0.26$
		1%	$12.09^{a} \pm 2.44$	$23.00^{abc} \pm 6.30$
		1.5%	$12.36^{a} \pm 2.83$	$24.27^{abc} \pm 8.36$
	GP	0.5%	$12.36^{a} \pm 3.34$	$25.09^{abc} \pm 4.89$
		1%	$9.82^{a} \pm 0.26$	$19.82^{abc} \pm 0.26$
		1.5%	$9.82^{a} \pm 0.26$	$22.82^{abc} \pm 2.96$
	BS	0.5%	$21.36^{a} \pm 13.50$	$14.00^{abc} \pm 2.57$
		1%	$9.91^{a} \pm 0.90$	$12.45^{a} \pm 0.64$
		1.5%	$10.36^{a} \pm 1.54$	$13.18^{abc} \pm 0.90$
IM	Control		$14.09^{a} \pm 4.50$	$24.91^{abc} \pm 13.11$
	CP	0.5%	$14.09^{a} \pm 3.99$	$24.82^{abc} \pm 13.50$
		1%	$16.27^{a} \pm 2.19$	$16.36^{abc} \pm 6.94$
		1.5%	$16.45^{a} \pm 2.44$	$16.27^{abc} \pm 7.07$
	GP	0.5%	$24.09^{a} \pm 14.27$	$20.09^{abc} \pm 3.73$
		1%	$13.73^{a} \pm 5.53$	$16.73^{abc} \pm 1.03$
		1.5%	$14.45^{a} \pm 4.24$	$16.82^{abc} \pm 1.41$
	BS	0.5%	$12.64^{a} \pm 0.13$	$12.64^{a} \pm 0.64$
		1%	$11.27^{a} \pm 0.77$	$12.64^{a} \pm 0.13$
		1.5%	$11.18^{a} \pm 0.64$	$13.09^{ab} \pm 0.26$

Note:
Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) do not differ significantly ($p > 0.05$). African spice, AS; Industrial marinade/pickle, IM; CP, Cranberry pomace; GP, Grape pomace; BS, Baikal Skullcap.

Changes in L*a*b* color, and cooking weight loss

The color stability of beef meat has been attributed to the presence of pigments, which ultimately depends on tissue composition and structure (*Hashemi Gahruie et al., 2017*). In this current work, the changes in L*a*b* color and cooking weight loss values of the various marinated oven-grilled beef entrecôte compared to control are respectively shown in Table 2 and Fig. 5. Varying range values of L*a*b* color (L*color: from 29.2 ± 2.4 at AS+GP 0.5% after oven-grill to 41.3 ± 1.7 at control +GP 1.0% after oven-grilling; a* color: from 2.15 ± 1.6 at IM +BS 1.5% after oven-grilling to 17.54 ± 0.82 at AS + BS 1.0%; b* color: from 3.9 ± 0.1 at control+ CP 1.0% to 15.76 ± 1.49 at IM +BS 0.5%) as well as cooking weight loss (for CP = from ~6.05% at IM with 0.5% antioxidant additive to ~46.03% at IM with no antioxidant additive; for GP = from ~29.92% at AS with no antioxidant additive to ~46.03% at IM with no antioxidant additive; for BS: from ~27.79 at control with no antioxidant additive to ~46.03% at IM with no antioxidant additive) were found. To establish a clear link when comparing color and cooking weight loss of different marinated oven-grilled beef entrecote samples seems difficult at this study. Other parameters, for instance, the pH and TBARS levels might corroborate the cooking weight loss of different marinated oven-grilled beef entrecote samples at this study. We opine this

Table 2 Changes in L*a*b* color of (a) cranberry pomace (CP) (b) grape pomace (GP), and (c) Baikal skullcap (BS) across the various marinated oven-grilled beef entrecôte meat samples.

(a) CP before and after oven-grill

Sample	CP before oven-grill			CP after oven-grill		
	L	a	b	L	a	b
1	32.4^{a} ± 2.3	14.5^{abc} ± 2.3	5.3^{ab} ± 1.0	36.1^{ab} ± 3.7	6.1^{abc} ± 1.9	9.8^{abc} ± 2.8
2	31.4^{a} ± 3.0	14.1^{abc} ± 1.1	3.9^{a} ± 0.1	39.6^{ab} ± 3.2	5.4^{ab} ± 1.1	8.2^{ab} ± 1.4
3	31.8^{a} ± 1.9	15.5^{bc} ± 3.3	6.4^{abc} ± 1.7	37.8^{ab} ± 3.0	4.1^{a} ± 0.5	6.7^{a} ± 0.7
4	32.7^{a} ± 2.0	16.9^{c} ± 2.1	8.6^{bcd} ± 1.2	40.9^{b} ± 4.3	4.8^{ab} ± 0.2	8.5^{abc} ± 1.3
5	33.1^{a} ± 1.2	14.5^{abc} ± 0.4	9.3^{cde} ± 1.2	40.5^{b} ± 6.4	6.0^{abc} ± 0.9	11.1^{bcd} ± 2.7
6	32.1^{a} ± 1.3	12.9^{abc} ± 4.2	12.7^{e} ± 1.4	34^{ab} ± 3.4	5.3^{ab} ± 2.1	9.0^{abc} ± 2.1
7	32.5^{a} ± 1.1	15.8^{bc} ± 1.2	10.6^{de} ± 1.7	36.7^{ab} ± 4.5	8.0^{c} ± 1.6	11.1^{bcd} ± 1.6
8	31.8^{a} ± 0.6	12.4^{ab} ± 0.6	10.5^{de} ± 1.4	39.4^{ab} ± 3.4	5.4^{ab} ± 1.0	11.5^{cd} ± 1.1
9	34.8^{a} ± 1.4	11.1^{a} ± 1.8	7.2^{abcd} ± 2.3	40.7^{b} ± 1.2	6.4^{abc} ± 0.7	14.6^{e} ± 1.2
10	34.5^{a} ± 2.9	14.6^{abc} ± 2.4	9.6^{cde} ± 3.3	35.6^{ab} ± 4.9	4.8^{ab} ± 2.5	9.9^{bc} ± 1.8
11	32.6^{a} ± 0.9	13.7^{abc} ± 2.4	10^{cde} ± 3.9	40^{ab} ± 1.3	4.0^{a} ± 0.5	8.5^{abc} ± 0.6
12	32.3^{a} ± 2.1	14.0^{abc} ± 1.6	7.5^{abcd} ± 1.2	32.8^{a} ± 3.7	6.9^{bc} ± 1.4	13.3^{de} ± 0.5

(b) GP before and after oven-grill

	GP before oven-grill			GP after oven-grill		
	L	a	b	L	a	b
1	33.3^{a} ± 1.6	17.0^{b} ± 2.1	10.3^{bcd} ± 1.5	35.6^{abcd} ± 1.9	4.1^{abc} ± 2.8	7.8^{ab} ± 2.5
2	33.9^{a} ± 3.4	16.0^{b} ± 1.0	5.3^{a} ± 2.1	41.3^{d} ± 1.7	3.6^{ab} ± 1.0	11.4^{bcd} ± 0.7
3	33.4^{a} ± 1.5	16.1^{b} ± 2.0	9.3^{abc} ± 1.1	34.5^{abcd} ± 6.1	3.5^{a} ± 2.2	7.1^{a} ± 1.9
4	33.6^{a} ± 4.5	11.0^{a} ± 3.2	6.3^{ab} ± 3.2	36.2^{abcd} ± 4.3	4.7^{abc} ± 0.4	10.1^{abc} ± 2.5
5	33.1^{a} ± 1.2	14.5^{b} ± 0.4	9.3^{abc} ± 1.2	40.5^{cd} ± 6.4	6.0^{abc} ± 0.9	11.1^{bcd} ± 2.7
6	33.1^{a} ± 2.7	13.4^{ab} ± 2.5	9.7^{abcd} ± 1.5	33.5^{abc} ± 4.4	3.5^{a} ± 1.5	6.5^{a} ± 2.0
7	35.3^{a} ± 1.9	14.9^{b} ± 0.7	13.5^{cd} ± 2.2	29.2^{a} ± 2.4	7.4^{c} ± 0.7	9.9^{abc} ± 1.0
8	33.3^{a} ± 1.2	15.6^{b} ± 0.4	10.1^{abcd} ± 4.0	31.3^{ab} ± 4.4	6.6^{abc} ± 2.7	9.0^{ab} ± 2.6
9	34.8^{a} ± 1.4	11.1^{a} ± 1.8	7.2^{ab} ± 2.3	40.7^{cd} ± 1.2	6.4^{abc} ± 0.7	14.6^{d} ± 1.2
10	32.7^{a} ± 1.6	15.5^{b} ± 2.3	9.8^{abcd} ± 2.0	36.9^{bcd} ± 3.1	5.4^{abc} ± 0.3	13.2^{cd} ± 0.3
11	31.2^{a} ± 1.4	15.2^{b} ± 1.0	14.4^{d} ± 2.8	29.5^{ab} ± 4.7	7.0^{bc} ± 2.3	8.6^{ab} ± 1.9
12	31.6^{a} ± 0.9	14.5^{b} ± 2.3	10.0^{abcd} ± 3.7	32.4^{ab} ± 3.2	5.2^{abc} ± 2.4	9.9^{abc} ± 3.3

(c) BS before and after oven-grill

	BS before oven-grill			BS after oven-grill		
	L	a	b	L	a	b
1	33.7^{a} ± 5.7	16.0^{cde} ± 3.1	7.2^{ab} ± 4.3	35.1^{ab} ± 3.8	7.7^{c} ± 3.0	10.1^{ab} ± 2.4
2	34.9^{a} ± 3.9	15.1^{bcde} ± 0.8	4.3^{a} ± 0.5	31.0^{a} ± 0.5	7.3^{c} ± 0.7	10.4^{ab} ± 1.0
3	35.8^{a} ± 0.7	13.9^{abcd} ± 1.8	12.4^{cde} ± 1.5	32.2^{a} ± 5.4	5.8^{abc} ± 2.6	8.8^{a} ± 1.6
4	33.2^{a} ± 0.5	15.7^{bcde} ± 0.7	3.9^{a} ± 0.9	37.4^{ab} ± 0.9	4.2^{abc} ± 1.2	8.0^{a} ± 1.8
5	33.1^{a} ± 1.2	14.5^{bcd} ± 0.4	9.3^{bc} ± 1.2	40.5^{b} ± 6.4	6.0^{bc} ± 0.9	11.1^{ab} ± 2.7
6	34.7^{a} ± 2.3	17.5^{e} ± 0.8	11.8^{cd} ± 3.6	33.4^{a} ± 1.5	5.6^{abc} ± 2.0	10.4^{ab} ± 3.2

Table 2 (continued)

(c) BS before and after oven-grill

	BS before oven-grill			BS after oven-grill		
	L	a	b	L	a	b
7	$34.3^{a} \pm 0.4$	$16.3^{de} \pm 0.8$	$4.8^{a} \pm 1.4$	$35.9^{ab} \pm 2.0$	$4.4^{abc} \pm 3.0$	$9.9^{ab} \pm 3.3$
8	$34.4^{a} \pm 3.2$	$13.9^{abcd} \pm 1.8$	$11.1^{c} \pm 1.2$	$32.3^{a} \pm 2.7$	$4.4^{abc} \pm 2.0$	$10.4^{ab} \pm 3.2$
9	$34.8^{a} \pm 1.4$	$11.1^{a} \pm 1.8$	$7.3^{ab} \pm 2.3$	$40.7^{b} \pm 1.2$	$6.4^{c} \pm 0.7$	$14.6^{b} \pm 1.2$
10	$31.9^{a} \pm 2.1$	$12.8^{ab} \pm 0.9$	$11.1^{c} \pm 2.2$	$34.9^{ab} \pm 3.5$	$2.5^{ab} \pm 1.6$	$9.4^{a} \pm 3.2$
11	$34.2^{a} \pm 2.7$	$13.2^{abc} \pm 2.6$	$15.8^{e} \pm 1.5$	$34.5^{ab} \pm 2.3$	$2.3^{a} \pm 1.3$	$9.2^{a} \pm 3.6$
12	$34.8^{a} \pm 1.7$	$13.6^{abcd} \pm 1.2$	$15.3^{de} \pm 1.0$	$35.7^{ab} \pm 5.2$	$2.2^{a} \pm 1.6$	$7.8^{a} \pm 3.2$

Note:

Results followed by the same lowercase letter(s) in the column of cutting force do not differ significantly ($p > 0.05$). The number representations for different color shades are as follows: (1) control (antioxidant additive %= 0.0); (2) control (antioxidant additive %= 0.5); (3) control (antioxidant additive %= 1.0); (4) control (antioxidant additive %= 1.5); (5) AS (antioxidant additive %= 0.0); (6) AS (antioxidant additive %= 0.5); (7) AS (antioxidant additive %= 1.0); (8) AS (antioxidant additive %= 1.5); (9) IM (antioxidant additive %= 0.0); (10) IM (antioxidant additive %= 0.5); (11) IM (antioxidant additive %= 1.0); (12) IM (antioxidant additive %= 1.5). African spice, AS; Industrial marinade/pickle, IM; The antioxidant additives include: (a) cranberry pomace (CP) (b) grape pomace (GP), and (c) Baikal skullcap (BS).

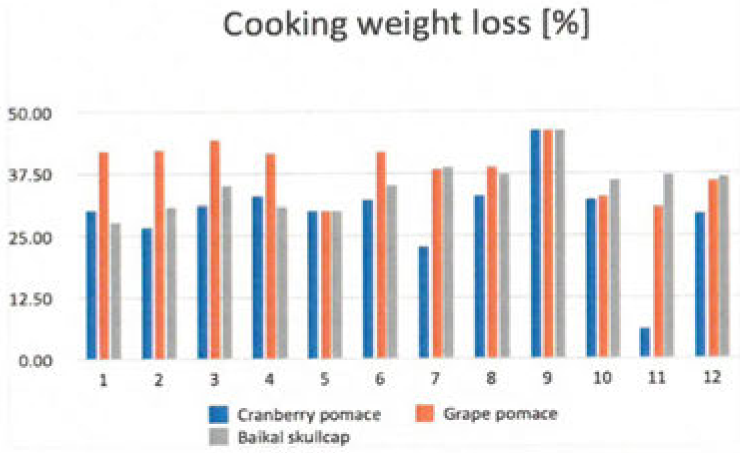

Figure 5 Changes in cooking weight loss (%) across the various marinated oven-grilled beef entrecôte meat samples. The number representations for different colour shades are as follows: (1) control (antioxidant additive %= 0.0); (2) control (antioxidant additive %= 0.5); (3) control (antioxidant additive %= 1.0); (4) control (antioxidant additive %= 1.5); (5) AS (antioxidant additive %= 0.0); (6) AS (antioxidant additive %= 0.5); (7) AS (antioxidant additive %= 1.0); (8) AS (antioxidant additive %= 1.5); (9) IM (antioxidant additive %= 0.0); (10) IM (antioxidant additive %= 0.5); (11) IM (antioxidant additive %= 1.0); (12) IM (antioxidant additive %= 1.5). African spice, AS; Industrial marinade/pickle, IM; The antioxidant additives include cranberry pomace, grape pomace, and Baikal skullcap.

Full-size DOI: 10.7717/peerj.15116/fig-5

because, earlier workers like Oreskovich et al. (1992), by evaluating how marinate pH influenced texture of beef meat, understood that cooking (weight) losses could reach 45% at pH 4.24 and 5.38, but tended to decrease at pH 6.66 and 8.01.

To a large degree, the high temperature of 180 °C and process duration of 5 min set for the oven-grilling at this current study would most likely be contributing to the cooking weight loss outcomes of the different marinated oven-grilled beef entrecote samples.

Probably, this heat treatment kickstarted the fibre contractions within the intramuscular connective tissue/muscle, which might have accounted for the differences in the cooking weight loss (*Ježek et al., 2020*). Besides oven grilling process to bring about some decreases in cooking weight loss, the physical condition of beef entrecôte muscle might not solely depend on the degree of moisture loss influence, but would include the anticipated infiltration of the marination variants. Alongside cooking weight loss, the application of oven-grilling across CP, GP and BS probably brought about some observable color trends, depicted by either increasing or decreasing $L^*a^*b^*$ values. For instance, whilst the oven-grilling largely increased the L^* color, and decreased the a^* color, it would largely fluctuate the b^* color scales of different marinated beef entrecôte meat samples.
An enhanced antioxidant effect should not reflect the decreases in a^* value, which would be required to stabilize the color (*Libera et al., 2018*). Feasibly also, the oven-grilling might have facilitated the range values of $L^*a^*b^*$ color as well as cooking weight to expand towards the extreme values, potentially supplemented by increment concentrations of CP, GP and BS, alongside the incorporation of AS or IM.

Changes in textural cutting force

Defined by certain homogeneous attributes and often adapted by food processing, meat texture often instrumentally determined explains key human physiological-psychological awareness of key rheological and associated properties (*Novaković & Tomašević, 2017*). In this current work, the changes in textural cutting force values of the various marinated oven-grilled beef entrecôte compared to control are shown in Table 3. Incorporating either AS or IM, the textural cutting force values showed promising ranges across CP (from 35.2 ± 5.83 N at IM without antioxidant additive, to 84.7 ± 10.28 N at IM +CP 1.5%), GP (from 35.2 ± 5.83 N at IM without antioxidant additive, to 83.8 ± 21.14 N at AS +GP 0.5%) and BS (from 35.2 ± 5.83 N at IM without antioxidant additive, to 70.3 ± 27.92 N at AS + BS 1.0%) samples. Probably, the CP, GP and BS concentrations might be increasing with textural cutting force.

Earlier workers like *Oreskovich et al. (1992)* understood that textural properties of beef meat are more likely to change in acidic compared to alkaline conditions. In this current work, higher textural cutting force values seemed to corroborate with samples that had more acidic-like pH values. Contextualizing this observation with the composition of muscle tissue, the connective aspects like myofibrillar proteins would help to build up the meat tenderness (*Migdał et al., 2020*). Moreover, any increase in the cutting force could associate with the cracking phenomena, which could happen within the muscle fibers to negatively influence the muscle tenderness (*Xia et al., 2012*). At slaughter, the meat structure would be affected as muscle glycogen increases with resistance to stress-induced (glycogen) depletion, alongside severe pH decreases (*Olsson & Pickova, 2005*). Whilst (beef) entrecôte samples comprise fat, connective tissue, as well as exudative juice, the muscle mass comprise between 35–60% of animal's total weight (*Redefine Meat, 2022*), all of which should be among the influential considerations that underpin the textural cutting force values of the various marinated oven-grilled beef entrecôte samples.

Table 3 Changes in textural cutting force across the various marinated grilled beef entrecôte meat samples compared to control.

nr	Antioxidant additive	Type of marinade	Percentage of antioxidant additive	Beef nutting force (N)
1	CP	Control	0.0	$67.5^{bcde} \pm 7.2$
2			0.5	$59.7^{abcde} \pm 4.8$
3			1.0	$69.5^{cde} \pm 11.8$
4			1.5	$57.6^{abcde} \pm 15.9$
5		AS	0.0	$68.7^{cde} \pm 5.2$
6			0.5	$35.6^{a} \pm 4.0$
7			1.0	$37.2^{ab} \pm 1.5$
8			1.5	$66.9^{bcde} \pm 11.5$
9		IM	0.0	$35.2^{a} \pm 5.8$
10			0.5	$59.2^{abcde} \pm 24.4$
11			1.0	$81.9d^{e} \pm 15.3$
12			1.5	$84.7^{e} \pm 10.3$
13	GP	Control	0.0	$81.5^{de} \pm 23.5$
14			0.5	$70.1^{cde} \pm 29.0$
15			1.0	$59.7^{abcde} \pm 10.8$
16			1.5	$60.9^{abcde} \pm 14.9$
17		AS	0.0	$68.7^{cde} \pm 5.2$
18			0.5	$83.8^{de} \pm 21.1$
19			1.0	$62.0^{abcde} \pm 8.6$
20			1.5	$47.9^{abc} \pm 4.3$
21		IM	0.0	$35.2^{a} \pm 5.8$
22			0.5	$40.6^{abc} \pm 11.8$
23			1.0	$67.5^{bcde} \pm 8.0$
24			1.5	$56.6^{abcde} \pm 2.6$
25	BS	Control	0.0	$64.9^{abcde} \pm 27.4$
26			0.5	$42.6^{abc} \pm 8.6$
27			1.0	$66.8^{bcde} \pm 10.6$
28			1.5	$68.0^{cde} \pm 31.5$
29		AS	0.0	$68.7^{cde} \pm 5.2$
30			0.5	$59.6^{abcde} \pm 7.9$
31			1.0	$70.3^{cde} \pm 27.9$
32			1.5	$53.5^{abcd} \pm 6.2$
33		IM	0.0	$35.2^{a} \pm 5.8$
34			0.5	$61.9^{abcde} \pm 34.9$
35			1.0	$54.3^{abcde} \pm 4.4$
36			1.5	$60.7^{abcde} \pm 7.8$

Note:
Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) in the column of cutting force do not differ significantly ($p > 0.05$). African spice, AS; Industrial marinade/pickle, IM; CP, Cranberry pomace; GP, Grape pomace; BS, Baikal skullcap.

Table 4 Sensory profile by way of flavour, appearance, tenderness, taste and flavour across the various marinated grilled beef entrecôte meat samples compared to control.

			Flavour	Apperance	Tenderness	Taste	Off flavor
Control	Control	0%	$3.57^{abcd} \pm 0.98$	$3.93^{a} \pm 1.10$	$2.43^{abc} \pm 1.27$	$3.00^{abcd} \pm 1.15$	$4.86^{ab} \pm 0.38$
	CP	0.5%	$2.79^{a} \pm 1.22$	$3.43^{a} \pm 1.72$	$3.43c^{def} \pm 0.53$	$3.79^{bcde} \pm 0.81$	$4.51^{ab} \pm 1.12$
		1%	$3.79^{abcd} \pm 0.57$	$4.29^{a} \pm 0.95$	$2.79^{abcde} \pm 0.81$	$3.36^{abcde} \pm 1.11$	$4.71^{ab} \pm 0.49$
		1.5%	$3.71^{abcd} \pm 0.76$	$3.86^{a} \pm 0.90$	$2.71^{abcd} \pm 0.76$	$3.14^{abcde} \pm 0.90$	$4.14^{ab} \pm 1.46$
	GP	0.5%	$3.88^{abcd} \pm 0.90$	$3.88^{a} \pm 0.69$	$1.88^{a} \pm 0.90$	$2.88^{abc} \pm 0.90$	$4.63^{ab} \pm 0.49$
		1%	$3.63^{abcd} \pm 0.95$	$3.88^{a} \pm 0.69$	$3.25^{bcdef} \pm 0.53$	$3.63^{bcde} \pm 0.53$	$4.63^{ab} \pm 0.38$
		1.5%	$3.63^{abcd} \pm 0.95$	$4.00^{a} \pm 0.58$	$1.88^{a} \pm 1.07$	$2.38^{a} \pm 1.11$	$3.88^{a} \pm 1.35$
	BS	0.5%	$3.31^{abcd} \pm 0.45$	$3.75^{a} \pm 0.61$	$3.69^{def} \pm 0.96$	$3.44^{abcde} \pm 0.70$	$5.00^{b} \pm 0.00$
		1%	$3.44^{abcd} \pm 0.39$	$3.63^{a} \pm 0.79$	$3.38^{cdef} \pm 0.91$	$3.52^{abcde} \pm 0.70$	$4.88^{ab} \pm 0.38$
		1.5%	$3.63^{abcd} \pm 0.53$	$3.69^{a} \pm 0.96$	$3.63^{cdef} \pm 1.17$	$3.25^{abcde} \pm 0.82$	$4.50^{ab} \pm 1.51$
AS	Control	0%	$3.64^{abcd} \pm 0.94$	$4.43^{a} \pm 0.79$	$3.06^{bcdef} \pm 1.09$	$3.50^{abcde} \pm 1.04$	$4.79^{ab} \pm 0.39$
	CP	0.5%	$3.21^{abc} \pm 1.68$	$3.50^{a} \pm 1.38$	$3.71^{def} \pm 0.76$	$3.37^{abcde} \pm 1.11$	$4.43^{ab} \pm 0.98$
		1%	$3.50^{abcd} \pm 1.19$	$3.29^{a} \pm 1.38$	$3.43^{cdef} \pm 0.84$	$4.36^{e} \pm 0.63$	$4.86^{ab} \pm 0.38$
		1.5%	$3.50^{abcd} \pm 0.96$	$3.93^{a} \pm 1.17$	$3.43^{cdef} \pm 0.79$	$4.29^{e} \pm 0.49$	$4.86^{ab} \pm 0.38$
	GP	0.5%	$4.13^{bcd} \pm 0.69$	$4.00^{a} \pm 0.69$	$2.75^{abcd} \pm 0.69$	$3.00^{abcd} \pm 0.57$	$4.38^{ab} \pm 0.53$
		1%	$4.50^{d} \pm 0.79$	$4.13^{a} \pm 0.76$	$2.75^{abcd} \pm 1.10$	$4.00^{cde} \pm 1.15$	$4.75^{ab} \pm 0.38$
		1.5%	$3.50^{abcd} \pm 1.13$	$3.38^{a} \pm 1.13$	$2.88^{abcdef} \pm 0.58$	$2.75^{ab} \pm 1.25$	$4.50^{ab} \pm 0.53$
	BS	0.5%	$3.57^{abcd} \pm 1.03$	$3.50^{a} \pm 1.03$	$3.38^{cdef} \pm 1.22$	$3.38^{abcde} \pm 0.48$	$4.38^{ab} \pm 1.50$
		1%	$2.88^{ab} \pm 0.79$	$3.19^{a} \pm 0.61$	$3.50^{cdef} \pm 0.76$	$3.56^{abcde} \pm 0.50$	$4.75^{ab} \pm 0.49$
		1.5%	$3.50^{abcd} \pm 1.11$	$3.56^{a} \pm 0.75$	$3.81^{def} \pm 0.94$	$3.88^{bcde} \pm 0.76$	$5.00^{b} \pm 0.00$
IM	Control	0%	$3.86^{abcd} \pm 1.21$	$3.14^{a} \pm 1.35$	$3.36^{cdef} \pm 1.38$	$3.5^{abcde} \pm 1.19$	$4.36^{ab} \pm 1.11$
	CP	0.5%	$3.43^{abcd} \pm 1.27$	$3.71^{a} \pm 1.38$	$2.86^{abcdef} \pm 1.35$	$3.29^{abcde} \pm 1.22$	$4.14^{ab} \pm 1.03$
		1%	$3.86^{abcd} \pm 0.69$	$3.79^{a} \pm 1.35$	$3.00^{abcdef} \pm 0.82$	$4.00^{cde} \pm 0.65$	$4.79^{ab} \pm 0.39$
		1.5%	$4.07^{bcd} \pm 0.73$	$4.36^{a} \pm 0.63$	$4.00^{ef} \pm 0.65$	$4.21^{de} \pm 0.81$	$4.86^{ab} \pm 0.38$
	GP	0.5%	$4.25^{cd} \pm 1.11$	$3.75^{a} \pm 1.07$	$3.75^{def} \pm 1.07$	$3.88^{bcde} \pm 1.00$	$4.75^{ab} \pm 0.38$
		1%	$3.88^{abcd} \pm 0.90$	$4.06^{a} \pm 0.58$	$3.00^{abcdef} \pm 0.90$	$2.94^{abc} \pm 1.21$	$4.00^{ab} \pm 1.53$
		1.5%	$4.06^{bcd} \pm 0.73$	$4.00^{a} \pm 0.82$	$3.13^{bcdef} \pm 1.11$	$4.00^{cde} \pm 0.82$	$4.25^{ab} \pm 1.11$
	BS	0.5%	$3.50^{abcd} \pm 1.38$	$3.38^{a} \pm 1.07$	$4.06^{f} \pm 0.84$	$3.44^{abcde} \pm 1.29$	$4.75^{ab} \pm 0.38$
		1%	$3.81^{abcd} \pm 0.63$	$4.00^{a} \pm 0.90$	$3.56^{cdef} \pm 0.50$	$3.94^{bcde} \pm 0.91$	$4.50^{ab} \pm 1.13$
		1.5%	$4.13^{bcd} \pm 1.41$	$3.31^{a} \pm 0.81$	$3.88^{def} \pm 1.11$	$3.63^{bcde} \pm 1.43$	$4.75^{ab} \pm 0.38$

Note:
Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) do not differ significantly ($p > 0.05$). African spice, AS; Industrial marinade/pickle, IM; Cranberry pomace, CP; Grape pomace, GP; Baikal skullcap, BS.

Changes in organoleptic aspects

Among key organoleptic attributes, it is believed that color, flavor and texture show strong influence on consumers' overall acceptability of meat products (*Hashemi Gahruie et al., 2017*). In this current work, the changes in organoleptic aspects of various marinated oven-grilled beef entrecôte samples, specifically by way of sensory and textural profiles, are shown in Tables 4 and 5. Either incorporating CP, GP and or BS, and even when involving control, AS and IM, there were minimum and maximum ranges found in sensory (Flavor: from 2.79 ± 1.22 at control+CP 0.5%, to 4.50 ± 0.79 at AS +GP 1%; Appearance: from 3.14

Table 5 Textural profile by way of hardness, chewiness, gumminess, graininess, and greasiness across the various marinated grilled beef entrecôte meat samples compared to control.

			Hardness	Chewiness	Gumminess	Graininess	Greasiness
Control	Control	0%	$5.86^{bcdefg} \pm 1.57$	$6.00^{abcdefgh} \pm 0.82$	$5.57^{abc} \pm 0.53$	$4.00^{a} \pm 1.41$	$3.00^{abc} \pm 1.41$
	CP	0.5%	$3.86^{ab} \pm 1.35$	$5.14^{abcdef} \pm 1.57$	$4.43^{abc} \pm 1.51$	$3.00^{a} \pm 2.00$	$2.86^{abc} \pm 1.21$
		1%	$7.00^{fgh} \pm 1.63$	$7.00^{fgh} \pm 1.15$	$5.14^{abc} \pm 1.57$	$3.29^{a} \pm 1.98$	$2.29^{ab} \pm 1.11$
		1.5%	$6.71^{efgh} \pm 1.11$	$6.29^{cdefgh} \pm 1.25$	$4.71^{abc} \pm 1.70$	$3.43^{a} \pm 1.72$	$3.29^{abc} \pm 2.43$
	GP	0.5%	$7.57^{gh} \pm 1.62$	$7.86^{gh} \pm 1.68$	$6.71^{c} \pm 2.06$	$2.57^{a} \pm 2.07$	$2.86^{abc} \pm 1.77$
		1%	$6.43^{defgh} \pm 1.27$	$5.86^{abcdefgh} \pm 1.07$	$4.57^{abc} \pm 2.23$	$3.43^{a} \pm 1.90$	$3.14^{abc} \pm 1.95$
		1.5%	$8.14^{h} \pm 1.77$	$8.00^{h} \pm 1.83$	$6.14^{abc} \pm 2.61$	$2.57^{a} \pm 2.30$	$3.43^{abc} \pm 2.37$
	BS	0.5%	$4.63^{abcde} \pm 2.45$	$5.13^{abcdef} \pm 1.72$	$4.38^{abc} \pm 2.51$	$2.63^{a} \pm 1.57$	$4.25^{abc} \pm 1.57$
		1%	$4.63^{abcde} \pm 1.70$	$5.25^{abcdef} \pm 1.38$	$4.63^{abc} \pm 1.99$	$3.00^{a} \pm 2.36$	$4.44^{abc} \pm 1.84$
		1.5%	$4.50^{abcde} \pm 1.11$	$5.00^{abcdef} \pm 1.89$	$5.25^{abc} \pm 1.41$	$2.75^{a} \pm 2.24$	$4.13^{abc} \pm 1.27$
AS	Control	0%	$5.71^{abcdefg} \pm 2.43$	$5.71^{abcdefg} \pm 2.43$	$4.71^{abc} \pm 2.56$	$3.29^{a} \pm 1.80$	$2.71^{ab} \pm 1.38$
	CP	0.5%	$4.29^{abcd} \pm 1.80$	$4.43^{abcd} \pm 2.15$	$4.15^{abc} \pm 2.12$	$3.86^{a} \pm 2.27$	$3.86^{abc} \pm 1.86$
		1%	$4.14^{abc} \pm 1.35$	$5.14^{abcdef} \pm 1.95$	$4.00^{ab} \pm 1.53$	$3.43^{a} \pm 1.51$	$3.29^{abc} \pm 1.70$
		1.5%	$5.71^{abcdefg} \pm 1.38$	$6.00^{abcdefgh} \pm 1.73$	$5.00^{abc} \pm 2.16$	$4.43^{a} \pm 1.40$	$2.57^{ab} \pm 1.27$
	GP	0.5%	$6.50^{defgh} \pm 2.10$	$5.43^{abcdef} \pm 2.07$	$5.00^{abc} \pm 1.73$	$2.57^{a} \pm 1.27$	$3.14^{abc} \pm 2.41$
		1%	$6.71^{efgh} \pm 1.38$	$6.00^{abcdefgh} \pm 1.41$	$6.14^{abc} \pm 1.95$	$2.43^{a} \pm 1.62$	$2.71^{ab} \pm 1.80$
		1.5%	$5.29^{abcdef} \pm 1.98$	$6.00^{abcdefgh} \pm 1.83$	$6.43^{bc} \pm 2.88$	$3.00^{a} \pm 1.63$	$2.86^{abc} \pm 2.12$
	BS	0.5%	$5.38^{abcdefg} \pm 2.43$	$4.88^{abcdef} \pm 2.37$	$5.50^{abc} \pm 2.14$	$3.38^{a} \pm 2.82$	$4.63^{bc} \pm 1.63$
		1%	$4.63^{abcde} \pm 1.50$	$4.88^{abcdef} \pm 1.27$	$3.75^{a} \pm 1.38$	$3.50^{a} \pm 2.07$	$4.50^{abc} \pm 1.98$
		1.5%	$4.63^{abcde} \pm 1.63$	$4.25^{abc} \pm 1.98$	$4^{ab} \pm 2.36$	$2.88^{a} \pm 2.12$	$4.38^{abc} \pm 1.29$
IM	CP	0%	$4.57^{abcde} \pm 1.72$	$4.86^{abcdef} \pm 2.12$	$3.86^{ab} \pm 2.12$	$3.43^{a} \pm 1.72$	$3.00^{abc} \pm 1.63$
		0.5%	$6.29^{cdefgh} \pm 2.06$	$6.57^{defgh} \pm 1.62$	$6.00^{abc} \pm 1.63$	$4.57^{a} \pm 2.15$	$3.43^{abc} \pm 2.23$
		1%	$6.29^{cdefgh} \pm 1.25$	$6.57^{cdefgh} \pm 1.40$	$6.00^{abc} \pm 1.91$	$3.86^{a} \pm 1.57$	$4.00^{abc} \pm 2.31$
		1.5%	$5.43^{abcdefg} \pm 2.15$	$5.43^{abcdef} \pm 2.23$	$5.00^{abc} \pm 2.52$	$3.71^{a} \pm 2.21$	$2.71^{ab} \pm 1.38$
	GP	0.5%	$4.43^{abcd} \pm 1.27$	$4.57^{abcde} \pm 1.81$	$3.71^{a} \pm 2.36$	$2.57^{a} \pm 1.51$	$2.14^{a} \pm 1.07$
		1%	$5.86^{bcdefg} \pm 2.19$	$5.86^{abcdefgh} \pm 2.41$	$6.00^{abc} \pm 2.45$	$2.86^{a} \pm 1.46$	$3.29^{abc} \pm 1.60$
		1.5%	$5.86^{bcdefg} \pm 2.67$	$5.29^{abcdef} \pm 2.63$	$5.43^{abc} \pm 2.70$	$2.43^{a} \pm 1.13$	$2.86^{abc} \pm 1.07$
	BS	0.5%	$3.50^{a} \pm 1.46$	$3.75^{a} \pm 1.57$	$4.13^{abc} \pm 1.70$	$3.63^{a} \pm 2.36$	$4.13^{abc} \pm 1.60$
		1%	$5.00^{abcdef} \pm 1.00$	$4.44^{abcd} \pm 1.27$	$4.19^{abc} \pm 1.68$	$3.38^{a} \pm 1.98$	$4.38^{abc} \pm 1.46$
		1.5%	$4.00^{ab} \pm 1.27$	$3.88^{ab} \pm 1.40$	$4.13^{abc} \pm 1.46$	$4.25^{a} \pm 3.10$	$3.75^{abc} \pm 0.95$

Note:
Results are expressed as mean ± standard deviation (SD). Results followed by the same lowercase letter(s) do not differ significantly ($p > 0.05$). African spice, AS; Industrial marinade/pickle, IM; Cranberry pomace, CP; Grape pomace, GP; Baikal skullcap, BS.

± 1.35 at IM without antioxidant additive, to 4.43 ± 0.79 at AS without antioxidant additive; Tenderness: from 1.88 ± 0.90 at control + GP 0.5%, to 4.06 ± 0.84 at IM+BS 0.5%; Taste: from 2.38 ± 1.11 at control +GP 1.5%, to 4.36 ± 0.63 at AS + CP 1.0%; Off-flavor: 3.88 ± 1.35 at control +GP 1.5%, to 5.00 ± 0.00 at either control+BS 0.5%, or AS +BS 1.5%), and textural (Hardness: from 3.86 ± 1.35 at control +CP 0.5%, to 8.14 ± 1.77 at control +GP 1.5%; Chewiness: from 3.75 ± 1.57 at IM+BS 0.5%, to 8.00 ± 1.83 at control+GP 1.5%; Gumminess: from 3.71 ± 2.36 at IM+GP 0.5%, to 6.71 ± 2.06 at control+GP 0.5%;

Graininess: from 2.43 ± 1.13 at IM +GP 1.5%, to 4.57 ± 2.15 at IM+CP 0.5%; Greasiness: from 2.14 ± 1.07 at IM+ GP 0.5%, to 4.63 ± 1.63 at AS +BS 0.5%) profiles.

The organoleptic attributes obtained some statistical differences ($p < 0.05$) as well as resemblances ($p > 0.05$) from sensory and textural standpoints. Specifically, such resemblances might suggest the panelists were unable to differentiate between some specific samples at this study. The fluctuating values would also suggest the increasing the CP, GP and BS concentrations appears not always going along with some of the sensorial and textural profile attributes. Interestingly, the panelists provided somewhat consistently higher off-flavour scores to most evaluated marinated oven-grilled beef entrecôte samples. The application of marinades is believed to have the ability to influence color of meat, yet not negatively when sensorially evaluated by panelists (*Siroli et al., 2020*). From the combination of instrumental texture and sensory tenderness acceptability, however, it should be possible to detect when beef meat toughness becomes unacceptable (*Schilling et al., 2003*). More so, differences in flavor, juiciness, and tenderness detectable by organoleptic evaluation may well suggest the preservative potential of marinades (*Kim et al., 2010*).

CONCLUSION

Different marinated oven-grilled beef entrecôte meat, specifically the resultant physicochemical and organoleptic attributes were investigated. Varying range values in pH, ABTS, DPPH, FRAP, TBARS, $L^*a^*b^*$ color scales, cooking weight loss, and textural cutting force, sensory and textural profile were detected. Moreover, the oven-grilling applied across CP, GP and BS largely produced some major color trends, which was either to increase or decrease the $L^*a^*b^*$ values. Also, increasing the CP, GP and BS concentrations might be help to increase the textural cutting force compared to control. The statistical differences and resemblances at organoleptic attributes were demonstrated by varying ranges, from sensory and textural profile standpoints. Considering that antioxidant values fell below control at some instances, the marinated oven-grilled beef entrecote samples of this work should have shelf promise. This has to be verified using different refrigerated packaging and storage conditions, during which the evaluation of other quality attributes like microbiological, volatile amines, amino acid as well as fatty acid/flavor profiles could be ascertained.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

Charles Odilichukwu R. Okpala, Katarzyna Leicht, Szymon Juchniewicz, and Małgorzata Korzeniowska received financial support from Wrocław University of Environmental and Life Sciences, Poland. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:
Wrocław University of Environmental and Life Sciences, Poland.

Competing Interests

Charles Odilichukwu R. Okpala is an Academic Editor for PeerJ.

Author Contributions

- Charles Odilichukwu R. Okpala conceived and designed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Szymon Juchniewicz performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Katarzyna Leicht performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Małgorzata Korzeniowska conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Raquel P. F. Guiné analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

Data Availability

The following information was supplied regarding data availability:

The raw data are available in the Supplemental File.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.15116#supplemental-information.

REFERENCES

Al-Dalali S, Li C, Xu B. 2022. Evaluation of the effect of marination in different seasoning recipes on the flavor profile of roasted beef meat via chemical and sensory analysis. *Journal of Food Biochemistry* **46(6)**:e13962 DOI 10.1111/jfbc.13962.

Ali MD, Kang GH, Yang HS, Jeong JY, Hwang YH, Park GB, Joo ST. 2007. A comparison of meat characteristics between duck and chicken breast. *Asian-Australas Journal of Animal Science* **20(6)**:1002–1006.

Amaral AB, Silva MVD, Lannes SCDS. 2018. Lipid oxidation in meat: mechanisms and protective factors-a review. *Journal of Food Science and Technology* **38(Suppl. 1)**:1–15 DOI 10.1590/fst.32518.

Amber K, Badawy NA, El-Sayd AENA, Morsy WA, Hassan AM, Dawood MA. 2021. Ginger root powder enhanced the growth productivity, digestibility, and antioxidative capacity to cope with the impacts of heat stress in rabbits. *Journal of Thermal Biology* **100**:103075 DOI 10.1016/j.jtherbio.2021.103075.

Augustyńska-Prejsnar A, Ormian M, Sokołowicz Z. 2017. The influence of frozen storage duration and thawing methods on the meat quality of broiler chickens. *Aparatura Badawcza i Dydaktyczna* **22(4)**:253–259.

Augustyńska-Prejsnar A, Ormian M, Sokołowicz Z. 2018. Physicochemical and sensory properties of broiler chicken breast meat stored frozen and thawed using various methods. *Journal of Food Quality* **2018** DOI 10.1155/2018/6754070.

Bai WK, Zhang FJ, He TJ, Su PW, Ying XZ, Zhang LL, Wang T. 2016. Dietary probiotic Bacillus subtilis strain fmbj increases antioxidant capacity and oxidative stability of chicken breast meat during storage. *PLOS ONE* **11(12)**:e0167339 DOI 10.1371/journal.pone.0167339.

Barido FH, Lee SK. 2022. Effect of detoxified *Rhus verniciflua* extract on oxidative stability and quality improvement of raw chicken breast during cold storage. *Journal of Animal Science and Technology* **64(2)**:380 DOI 10.5187/jast.2022.e20.

Beef2live. 2022. Entrecote. *Available at https://beef2live.com/story-entrecote-0-111968* (accessed 25 October 2022).

Berger J, Kim YHB, Legako JF, Martini S, Lee J, Ebner P, Zuelly SMS. 2018. Dry-aging improves meat quality attributes of grass-fed beef loins. *Meat Science* **145**:285–291 DOI 10.1016/j.meatsci.2018.07.004.

Brambila GS, Bowker BC, Zhuang H. 2016. Comparison of sensory texture attributes of broiler breast fillets with different degrees of white striping. *Poultry Science* **95(10)**:2472–2476 DOI 10.3382/ps/pew165.

Çakmakçı S, Topdaş EF, Kalın P, Han H, Şekerci P, Köse PL, Gülçin İ. 2015. Antioxidant capacity and functionality of oleaster (*E laeagnus angustifolia* L.) flour and crust in a new kind of fruity ice cream. *International Journal of Food Science & Technology* **50(2)**:472–481 DOI 10.1111/ijfs.12637.

Cheok CY, Chin NL, Yusof YA, Mustapa Kamal SM, Sazili AQ. 2011. Effect of marinating temperatures on physical changes of traditionally marinated beef satay. *Journal of Food Processing and Preservation* **35(4)**:474–482 DOI 10.1111/j.1745-4549.2010.00490.x.

Civille GV, Thomas Carr B. 2015. *Sensory Evaluation Techniques*. 5th Edition. Boca Raton: CRC Press, 632.

Clinquart A, Ellies-Oury MP, Hocquette JF, Guillier L, Santé-Lhoutellier V, Prache S. 2022. On-farm and processing factors affecting bovine carcass and meat quality. *Animal* **16**:100426 DOI 10.1016/j.animal.2021.100426.

Cook R. 2022. World beef production by country, Beef2Live. *Available at https://beef2live.com/story-world-beef-production-country-0-106880* (accessed 01 November 2022).

Domaradzki P, Stanek P, Litwińczuk Z, Skałecki P, Florek M. 2017. Slaughter value and meat quality of suckler calves: a review. *Meat Science* **134(1)**:135–149 DOI 10.1016/j.meatsci.2017.07.026.

FAO. 2022. Animal production and health division: meat & meat products. *Available at https://www.fao.org/agriculture/animal-production-and-health/en/* (accessed 04 September 2022).

Farhadian A, Jinap S, Abas F, Sakar ZI. 2010. Determination of polycyclic aromatic hydrocarbons in grilled meat. *Food Control* **21(5)**:606–610 DOI 10.1016/j.foodcont.2009.09.002.

Geletu US, Usmael MA, Mummed YY, Ibrahim AM. 2021. Quality of cattle meat and its compositional constituents. *Veterinary Medicine International* **2021(3)**:7340495 DOI 10.1155/2021/7340495.

Gómez I, Ibañez FC, Beriain MJ. 2019. Physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations. *International Journal of Food Properties* **22(1)**:1693–1708 DOI 10.1080/10942912.2019.1666869.

Hashemi Gahruie H, Hosseini SMH, Taghavifard MH, Eskandari MH, Golmakani MT, Shad E. 2017. Lipid oxidation, color changes, and microbiological quality of frozen beef burgers incorporated with shirazi thyme, cinnamon, and rosemary extracts. *Journal of Food Quality* **2017**:1–9 DOI 10.1155/2017/6350156.

Istrati D, Constantin O, Ionescu A, Vizireanu C, Dinică R. 2011. Study of the combined effect of spices and marination on beef meat vacuum packaged. *The Annals of the University Dunarea de Jos of Galati* **35(2)**:75–85.

Ježek F, Kameník J, Macharáčková B, Bogdanovičová K, Bednář J. 2020. Cooking of meat: effect on texture, cooking loss and microbiological quality-a review. *Acta Veterinaria Brno* **88(4)**:487–496 DOI 10.2754/avb201988040487.

Kerth CR, Blair-Kerth LK, Jones WR. 2003. Warner bratzler shear force repeatability in beef longissimus steaks cooked with a convection oven, broiler, or clam shell grill. *Journal of Food Science* **68(2)**:668–669 DOI 10.1111/j.1365-2621.2003.tb05729.x.

Khan MI, Min JS, Lee SO, Yim DG, Seol KH, Lee M, Jo C. 2015. Cooking, storage, and reheating effect on the formation of cholesterol oxidation products in processed meat products. *Lipids, Health & Disease* **14(1)**:1–9 DOI 10.1186/s12944-015-0091-5.

Kim J, Bang J, Beuchat LR, Kim H, Ryu JH. 2012. Controlled fermentation of kimchi using naturally occurring antimicrobial agents. *Food Microbiology* **32(1)**:20–31 DOI 10.1016/j.fm.2012.05.007.

Kim YJ, Jin SK, Park WY, Kim BW, Joo ST, Yang HS. 2010. The effect of garlic or onion marinade on the lipid oxidation and meat quality of pork during cold storage. *Journal of Food Quality* **33**:171–185 DOI 10.1111/j.1745-4557.2010.00333.x.

Kondjoyan A, Kohler A, Realini CE, Portanguen S, Kowalski R, Clerjon S, Gatellier P, Chevolleau S, Bonny JM, Debrauwer L. 2014. Towards models for the prediction of beef meat quality during cooking. *Meat Science* **97(3)**:323–331 DOI 10.1016/j.meatsci.2013.07.032.

Kopec W, Jamroz D, Wiliczkiewicz A, Biazik E, Pudlo A, Korzeniowska M, Hikawczuk T, Skiba T. 2020. Antioxidative characteristics of chicken breast meat and blood after diet supplementation with carnosine, L-histidine, and β-alanine. *Antioxidants* **9(11)**:1093 DOI 10.3390/antiox9111093.

Korkeala H, Mäki-Petäys O, Alanko T, Sorvettula O. 1986. Determination of pH in meat. *Meat Science* **18(2)**:121–132 DOI 10.1016/0309-1740(86)90088-4.

Lee KJ, Jung PM, Oh YC, Song NY, Kim T, Ma JY. 2014. Extraction and bioactivity analysis of major flavones compounds from Scutellaria baicalensis using *in vitro* assay and online screening HPLC-ABTS system. *Journal of Analytical Methods in Chemistry* **2014(1)**:1–15 DOI 10.1155/2014/150509.

Lengkidworraphiphat P, Wongpoomchai R, Taya S, Jaturasitha S. 2020. Effect of genotypes on macronutrients and antioxidant capacity of chicken breast meat. *Asian-Australasian Journal of Animal Sciences* **33(11)**:1817–1823 DOI 10.5713/ajas.19.0736.

Libera J, Kononiuk A, Kęska P, Wójciak K. 2018. Use of grape seed extract as a natural antioxidant additive in dry-cured pork neck technology. *Food Science and Biotechnology* **82(2)** DOI 10.34658/bfs.2018.82.2.141-150.

Listrat A, Lebret B, Louveau I, Astruc T, Bonnet M, Lefaucheur L, Picard B, Bugeon J. 2016. How muscle structure and composition influence meat and flesh quality. *The Scientific World Journal* **2016(6)**:1–14 DOI 10.1155/2016/3182746.

Luciano G, Moloney AP, Priolo A, Rohrle FT, Vasta V, Biondi L, Monahan FJ. 2011. Vitamin E and polyunsaturated fatty acids in bovine muscle and the oxidative stability of beef from cattle receiving grass or concentrate-based rations. *Journal of Animal Science* **89**:3759–3768 DOI 10.2527/jas.2010-3795.

Martini S, Cattivelli A, Conte A, Tagliazucchi D. 2021. Black, green, and pink pepper affect differently lipid oxidation during cooking and *in vitro* digestion of meat. *Food Chemistry* **350(8)**:129246 DOI 10.1016/j.foodchem.2021.129246.

McGlone JJ. 2013. The future of pork production in the world: towards sustainable, welfare-positive systems. *Animals* **3(2)**:401–415 DOI 10.3390/ani3020401.

Migdał W, Różycki M, Mucha A, Tyra M, Natonek-Wiśniewska M, Walczycka M, Kulawik P, Węsierska E, Zając M, Tkaczewska J, Migdał Ł, Krępa-Stefanik K. 2020. Meat texture profile and cutting strength analyses of pork depending on breed and age. *Annals of Animal Science* **20(2)**:677–692 DOI 10.2478/aoas-2019-0085.

Moroney NC, O'Grady MN, Lordan S, Stanton C, Kerry JP. 2015. Seaweed polysaccharides (laminarin and fucoidan) as functional ingredients in pork meat: an evaluation of anti-oxidative potential, thermal stability and bioaccessibility. *Marine Drugs* **13(4)**:2447–2464 DOI 10.3390/md13042447.

Muga FC, Marenya MO, Workneh TS. 2021. Modelling the thin-layer drying kinetics of marinated beef during infrared-assisted hot air processing of biltong. *International Journal of Food Science* **2021(11)**:1–14 DOI 10.1155/2021/8819780.

Nieuwsbericht. 2022. The potential for development of Polish beef. *Available at https://www.agroberichtenbuitenland.nl/actueel/nieuws/2022/03/02/the-potential-for-development-of-polish-beef* (accessed 26 October 2022).

Novaković S, Tomašević I. 2017. A comparison between Warner-Bratzler shear force measurement and texture profile analysis of meat and meat products: a review. *IOP Conference Series: Earth and Environmental Science* **85**:012063 DOI 10.1088/1755-1315/85/1/012063.

Okpala COR, Juchniewicz S, Leicht K, Skendrović H, Korzeniowska M, Guiné RP. 2023. Quality attributes of different marinated oven-grilled pork neck meat. *International Journal of Food Properties* **26(1)**:453–470 DOI 10.1080/10942912.2023.2166952.

Olsson V, Pickova J. 2005. The influence of production systems on meat quality, with emphasis on pork. *AMBIO: A Journal of the Human Environment* **34(4)**:338–343 DOI 10.1579/0044-7447-34.4.338.

Onopiuk A, Kołodziejczak K, Szpicer A, Wojtasik-Kalinowska I, Wierzbicka A, Półtorak A. 2021. Analysis of factors that influence the PAH profile and amount in meat products subjected to thermal processing. *Trends in Food Science & Technology* **115(2–4)**:366–379 DOI 10.1016/j.tifs.2021.06.043.

Open Textbooks. 2022. Composition of meat, in: meat cutting and processing for food service. *Available at https://opentextbc.ca/meatcutting/chapter/composition-of-meat/* (accessed 02 November 2022).

Oreskovich DC, Bechtel PJ, McKeith FK, Novakofski J, Basgall EJ. 1992. Marinade pH affects textural properties of beef. *Journal of Food Science* **57(2)**:305–311 DOI 10.1111/j.1365-2621.1992.tb05482.x.

Pereira V, López-Alonso M, Miranda M, Benedito JL, Garcia-Vaquero M. 2017. Relationship between the essential and toxic element concentrations and the proximate composition of different commercial and internal cuts of young beef. *European Food Research and Technology* **243**:1869–1873 DOI 10.1007/s00217-017-2888-0.

Purchas RW. 1990. An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Science* **27(2)**:129–140 DOI 10.1016/0309-1740(90)90061-A.

Redefine Meat. 2022. Understanding the science behind meat composition. Rehovot: Redefine Meat Ltd. *Available at https://www.redefinemeat.com/blog/structure-of-meat/* (accessed 10 March 2023).

Richardson P. 2004. *Improving the Thermal Processing of Foods.* Cambridge: Woodhead Publishing Limited, 520.

Roopchand DE, Krueger CG, Moskal K, Fridlender B, Lila MA, Raskin I. 2013. Food-compatible method for the efficient extraction and stabilization of cranberry pomace polyphenols. *Food Chemistry* **141(4)**:3664–3669 DOI 10.1016/j.foodchem.2013.06.050.

Santos D, Monteiro MJ, Voss HP, Komora N, Teixeira P, Pintado M. 2021. The most important attributes of beef sensory quality and production variables that can affect it: a review. *Livestock Science* **250**:104573 DOI 10.1016/j.livsci.2021.104573.

Sáyago-Ayerdi SG, Brenes A, Goñi I. 2009. Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. *LWT—Food Science and Technology* **42(5)**:971–976 DOI 10.1016/j.lwt.2008.12.006.

Schilling MW, Schilling JK, Claus JR, Marriott NG, Duncan SE, Wang H. 2003. Instrumental texture assessment and consumer acceptability of cooked broiler breasts evaluated using a geometrically uniform-shaped sample. *Journal of Muscle Foods* **14(1)**:11–23 DOI 10.1111/j.1745-4573.2003.tb00342.x.

Schröder MJA. 2003. *Food Quality and Consumer Value: Delivering Food that Satisfies.* Berlin, Heidelberg: Springer, 346.

Shahidi F, Hossain A. 2018. Bioactives in spices, and spice oleoresins: phytochemicals and their beneficial effects in food preservation and health promotion. *Journal of Food Bioactives* **3**:8–75 DOI 10.31665/JFB.2018.3149.

Siroli L, Baldi G, Soglia F, Bukvicki D, Patrignani F, Petracci M, Lanciotti R. 2020. Use of essential oils to increase the safety and the quality of marinated pork loin. *Foods* **9(8)**:987 DOI 10.3390/foods9080987.

Sokołowicz Z, Augustyńska-Prejsnar A, Krawczyk J, Kačániová M, Kluz M, Hanus P, Topczewska J. 2021. Technological and sensory quality and microbiological safety of rir chicken breast meat marinated with fermented milk products. *Animals* **11(11)**:3282 DOI 10.3390/ani11113282.

SustainBeef. 2021. European and national overview of beef production. *Available at https://www6.inrae.fr/sustainbeef/Project/WP2.1-Description-of-beef-production-systems/WP2.1.1-Beef-production-national-statistics* (accessed 01 November 2022).

Szymańska EJ. 2015. Functioning of the supply chain of pork in Poland. *Journal of Agribusiness and Rural Development* **3(37)**:555–563 DOI 10.17306/JARD.2015.59.

TasteAtlas. 2023. Entrecôte (Rib-Eye, Scotch Fillet, Delmonico (Cut)). Smalahove: AtlasMedia Ltd. *Available at https://www.tasteatlas.com/entrecote.*

Teplá JL, Dostálová T, Lužová D, Rožnovská J, Přichystalová L, Kalhotka L, Dvořák L, Sýkora V, Šustová K. 2013. Antimicrobial effects of selected plant extracts on the shelf life of goat whey. *MendelNet*, 614–620.

Thomas RH, Bernards MA, Drake EE, Guglielmo CG. 2010. Changes in the antioxidant activities of seven herb-and spice-based marinating sauces after cooking. *Journal of Food Composition and Analysis* **23(3)**:244–252 DOI 10.1016/j.jfca.2009.08.019.

Toldrá F, Flores M. 2000. The use of muscle enzymes as predictors of pork meat quality. *Food Chemistry* **69(4)**:387–395 DOI 10.1016/S0308-8146(00)00052-2.

Viegas O, Amaro LF, Ferreira IM, Pinho O. 2012. Inhibitory effect of antioxidant-rich marinades on the formation of heterocyclic aromatic amines in pan-fried beef. *Journal of Agricultural and Food Chemistry* **60(24)**:6235–6240 DOI 10.1021/jf302227b.

Vișan VG, Chiș MS, Păucean A, Mureșan V, Pușcaș A, Stan L, Vodnar DC, Dulf FV, Țibulcă D, Vlaic BA, Rusu IE, Kadar CB, Vlaic A. 2021. Influence of marination with aromatic herbs and cold pressed oils on black angus beef meat. *Foods* **10(9)**:2012 DOI 10.3390/foods10092012.

Xia X, Kong B, Liu J, Diao X, Liu Q. 2012. Influence of different thawing methods on physicochemical changes and protein oxidation of porcine longissimus muscle. *LWT—Food Science and Technology* **46(1)**:280–286 DOI 10.1016/j.lwt.2011.09.018.

Xiong YL. 2022. Muscle protein oxidation and functionality: a global view of a once-neglected phenomenon. *Meat and Muscle Biology* **5(3)**:14349 DOI 10.22175/mmb.14349.

Żakowska-Biemans S, Pieniak Z, Gutkowska K, Wierzbicki J, Cieszyńska K, Sajdakowska M, Kosicka-Gębska M. 2017. Beef consumer segment profiles based on information source usage in Poland. *Meat Science* **124(3)**:105–113 DOI 10.1016/j.meatsci.2016.11.001.

Zhang H, Wu J, Guo X. 2016. Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality. *Food Science and Human Wellness* **5(1)**:39–48 DOI 10.1016/j.fshw.2015.11.003.

Zhang Y, Henning SM, Lee RP, Huang J, Zerlin A, Li Z, Heber D. 2015. Turmeric and black pepper spices decrease lipid peroxidation in meat patties during cooking. *International Journal of Food Sciences and Nutrition* **66(3)**:260–265 DOI 10.3109/09637486.2014.1000837.

04 czerwca 2023 r

(miejscowość i data)

...Charles Odilichukwu R. OKPALA...

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy ...... *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023b). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ Life and Environment 11, e15116* .... mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

Okpala

04 June 2023.............

data i podpis

Wrocław 03.04.2023

mgr inż. Szymon Juchniewicz
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ Life and Environment 11, e15116* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

3.04.2023 Juchniewicz Szymon

Wrocław 03.04.2023

mgr inż. Katarzyna Leicht
Katedra Rozwoju Funkcjonalnych
Produktów Żywnościowych;
Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ Life and Environment 11, e15116* mój udział polegał na projektowaniu układu doświadczenia oraz modelu wykonanych badań, przeprowadzeniu doświadczenia, zebraniu i opracowaniu wyników.

03.04.2023, Katarzyna Leicht

dr hab. Małgorzata Korzeniowska, prof. uczelni 03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ Life and Environment 11, e15116* mój udział polegał na uczestnictwie w konceptualizacji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

…Prof Dr. hab. Raquel P.F. Guine…. 01 czerwca 2023 r

imię i nazwisko (miejscowość i data)

Polytechnic Institute of Viseu, Portugal….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Juchniewicz, S., Leicht, K., Korzeniowska, M., & Guiné, R. P. F. (2023). Marinated oven-grilled beef entrecôte meat from a bovine farm: Evaluation of resultant physicochemical and organoleptic attributes. PeerJ Life and Environment 11, e15116*… mój udział współnadzorował prace projektowe, udzielał wglądu w metodologię, uczestniczył w walidacji/wizualizacji danych oraz w rewizji projektu pracy.

15. May 2023

…………………………………

data i podpis

foods

MDPI

Communication

Assessing Nigerian Butchers' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis

Charles Odilichukwu R. Okpala [1,*], Obichukwu Chisom Nwobi [2] and Małgorzata Korzeniowska [1]

[1] Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wrocław University of Environmental and Life Sciences, 51-630 Wrocław, Poland; malgorzata.korzeniowska@upwr.edu.pl

[2] Department of Veterinary Public Health and Preventive Medicine, University of Nigeria Nsukka, 410001 Nsukka, Nigeria; obichukwu.nwobi@unn.edu.ng

* Correspondence: charlesokpala@gmail.com

Abstract: In Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) guides the inspection and production of beef meat and prescribes the good practices pertinent to beef products' handling, processing, and packaging. Specifically, good hygiene practice (GHP) assures beef product safety and consumer protection, whereas good storage practice (GSP) assures the continuity of hygiene activities within the storage stages. Relevant literature about butchers' knowledge and perception of good hygiene and storage practices within Nigeria slaughterhouses remains scant. This current study, therefore, assessed butchers' knowledge and perception of good hygiene and storage practices through a cattle slaughterhouse case analysis. The selected cattle slaughterhouse serves the increasingly thriving Nsukka beef market in Enugu State, Nigeria. Content validation was utilised to authenticate the questionnaire items, which were administered face-to-face to the respondents (i.e., the butchers). The questionnaire included a total of 30 questions. The results showed that the butchers were male (Freq. = 100%, n = 50), acquired their knowledge informally (Freq. = 88%, n = 44), were largely with more than 5 years of slaughterhouse experience (Freq. = 82%, n = 41), and were strongly ($p < 0.0001$) familiar with good hygiene (Freq. = 96%, n = 48) and storage (Freq. = 98%, n = 49) practices. The butchers provided examples that demonstrated knowledge and perception aspects of GHP and GSP. The perception aspects of GHP and GSP were correlated more, compared to knowledge and knowledge versus perception. Very conscious of their knowledge and perception of good hygiene and storage practices, the butchers herein have to strive for continuous improvement in their slaughterhouse activities to assure beef quality and consumer safety.

Keywords: butchers; cattle industry; food safety; food hygiene; healthy workplace; slaughterhouse

check for updates

Citation: Okpala, C.O.R.; Nwobi, O.C.; Korzeniowska, M. Assessing Nigerian Butchers' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods* **2021**, *10*, 1165. https://doi.org/10.3390/foods10061165

Academic Editors: Alessandra Guidi and Beniamino T. Cenci-Goga

Received: 6 April 2021
Accepted: 20 May 2021
Published: 22 May 2021

1. Introduction

Globally, the demand for beef is continually on the rise, providing a highly desirable eating experience, even in developing countries [1]. In Africa, livestock production remains a very important aspect of the agro-ecological landscape [2]. Cattle are among the most important livestock species reared via traditional pastoral farming systems, particularly within northern Nigeria [3]. The cost of beef meat is less in the northern part compared to the southern part of Nigeria. Despite this, beef meat remains the major animal protein consumption resource [4] across households, communities, states, and the entire country. For the meat industry to thrive, there has to be a strategy that integrates the livestock value chain, consumers, and producers. Although Nigeria's livestock industry appears not to be rapidly growing relative to the population that relies on it for beef, the number of grazing livestock as of 2010 was 108.6 million [5]. Notwithstanding meat processing largely dependent on livestock production [6,7], the beef market value creates employment and generates income for butchers. Equally, slaughtering and dressing cattle comes at a reasonable cost [4]. According to the Food and Agriculture Organisation (FAO) of the United Nations, meat products, either in fresh or frozen conditions, very rapidly become highly susceptible to microbial contamination as soon as they are exposed. It is exactly this situation that makes the hygiene of meat processing very relevant [8]. In addition, butchers at slaughterhouses in Nigeria, probably owing to their contact with a sizeable number of slaughtered cattle, could be exposed to zoonotic diseases [9], which makes relevant the need for optimum hygiene and storage practices.

In Nigeria, the Food Safety and Applied Nutrition (FSAN) Directorate under the National Agency for Food and Drug Administration and Control (NAFDAC) guides the inspection as well as the production at small–medium food enterprises and prescribes the minimum good hygiene practices (GHPs) pertinent during manufacturing, processing, and packaging, which are very applicable to cattle beef products. The fundamental aim is to assure both (meat) product safety and consumer protection. Further, beef production necessitates that technical skills, as well as equipment, be adequate and meet the regulated quality control standards [10]. Through the Federal Ministry of Health in Nigeria, the food safety management strategies provide the meat industry with prerequisite GHP regulatory guidelines [11]. Additionally, quality control mechanisms within the slaughterhouse environment, the butchers' workspace in particular, must operate optimally to curb any form of bacterial/zoonotic contamination [12,13]. GHP essential measures, very relevant at each stage of the supply chain, appear strongly associated with food production, quality, and safety [14,15]. Good storage practice (GSP) on the other hand, and specific to the meat industry, considers incoming material storage to finished product storage. GSP ensures that there is continuity of hygiene activities in the meat-processing stage, e.g., after the first washing of beef, it is either frozen or refrigerated [16,17]. Effective beef storage is among the means of implementing good practice. It involves high discipline standards from personnel and documentation to storage environment/facilities [16].

Described in codes of practice and largely designed by government bodies, good practices are known to involve quality assurance activities, which have to adhere to the control of food production and its associated processes [18]. Good practices form the crux of food quality and consumer protection, as well as within the agro-food industry. In addition to actualising the desired successes for food quality and consumer protection, the functioning of good practices ought to cut across all the production processes of agro-food products [19] and certainly to all the relevant facets of the meat industry. A schematic representation of the interaction of three key good practices applicable and relevant to a typical slaughterhouse in Nigeria is depicted in Figure 1. From cattle arriving in good condition (representing good agriculture practice (GAP)) to preparation for slaughter, the actual slaughter process, and the (immediate) carcass handling procedures after slaughter (representing GHP) to all aspects of carcass storage and sale procedures (representing GSP), there appears areas where these three clearly interact. Presumably, cattle rearers are largely involved with GAP, whereas GHP and GSP are of emphasis in the cattle slaughterhouse.

In contrast with developed countries, butchers in Nigeria largely operate under the administration and registration of the respective local government area (LGA) where the slaughterhouse is situated. In addition, the LGA mandates the butchers to work responsibly within their respective slaughterhouses, consistent with good hygiene and storage practices. What butchers know and perceive about good hygiene and storage practices would help the local, state, and federal governments, together with stakeholders, formulate problem-solving strategies for the cattle/meat industry. However, relevant literature about what butchers in Nigeria know and perceive of good hygiene and storage practices within the slaughterhouses where they work remains very scant. In this context, this current study aimed to assess butchers' knowledge and perception of good hygiene and storage practices through a case analysis of a cattle slaughterhouse that serves the increasingly thriving Nsukka beef market in Enugu State, Nigeria.

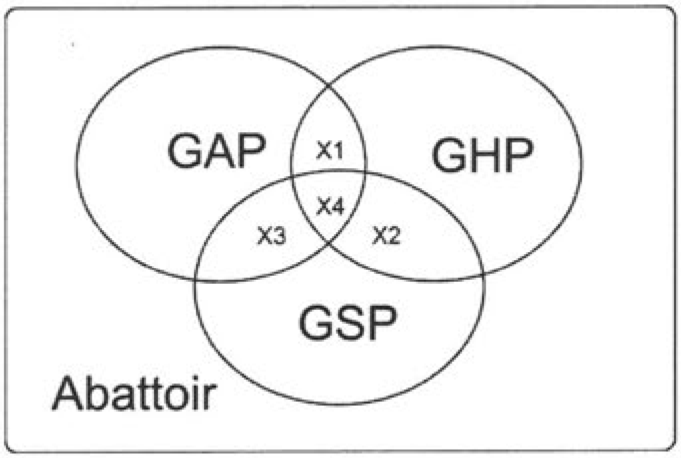

Figure 1. Schematic representation of the interaction of three key good practices applicable and relevant to a typical cattle abattoir/slaughterhouse in Nigeria. GAP = Good Agricultural Practice, which can involve the humane handling of cattle as well as pre-slaughter keeping of cattle at lairage; GHP = Good Hygiene Practice, which can involve slaughtering activity, as well as carcass splitting and inspection activities; GSP = Good Storage Practice, which can involve carcass storage and refrigeration; X1, X2, and X3 represent the interactive spaces of GAP × GHP, GHP × GSP, and GAP × GSP, respectively. In addition, X4 represents the interaction of GAP × GHP × GSP.

2. Study Subjects and Methods

2.1. Schematic Overview of Current Study

The schematic overview of the current study, from the identification of the study area/target population and development of the research instrument to delineating the results and discussions using the existing body of knowledge, is shown in Figure 2. For emphasis, this current work was designed to assess Nigerian butchers' knowledge and perception of good hygiene and storage practices via a case analysis of a cattle slaughterhouse. Essentially, this specific slaughterhouse was selected because of its important role, from receiving and slaughtering the cattle and processing and packaging the beef to supplying the beef to the Nsukka market (Enugu State, Nigeria).

2.2. Ethical Approval

Institutional ethics approval was not required for this study for the reason that it was strictly a questionnaire-based survey. However, the approval to use the research instrument for this survey was given by the slaughterhouse association. Additionally, this study adhered to the code of ethics of the World Medical Association Declaration of Helsinki [20]. Specifically, the informed consent was orally obtained from all butchers who participated in this study. In addition, the butchers' participation at this study was voluntary.

2.3. Study Area and Target Population

The study area was Nsukka urban in Enugu State, Nigeria. Specifically, Nsukka urban is situated at latitude 6°45′ and 7° N and longitude 7°12.5′ and 7°36′ E. With a population increasing beyond 1.26 million, Nsukka is a well-known local government area (LGA) that situates an ever-growing metropolis/university community [21]. Butchers within the Nsukka slaughterhouse were the target population, who by experience, expertise, and delivery of services are typically representative of other slaughterhouses in terms of size, volume, as well as workforce, not only situated in various communities/LGAs around the state but also around the entire country.

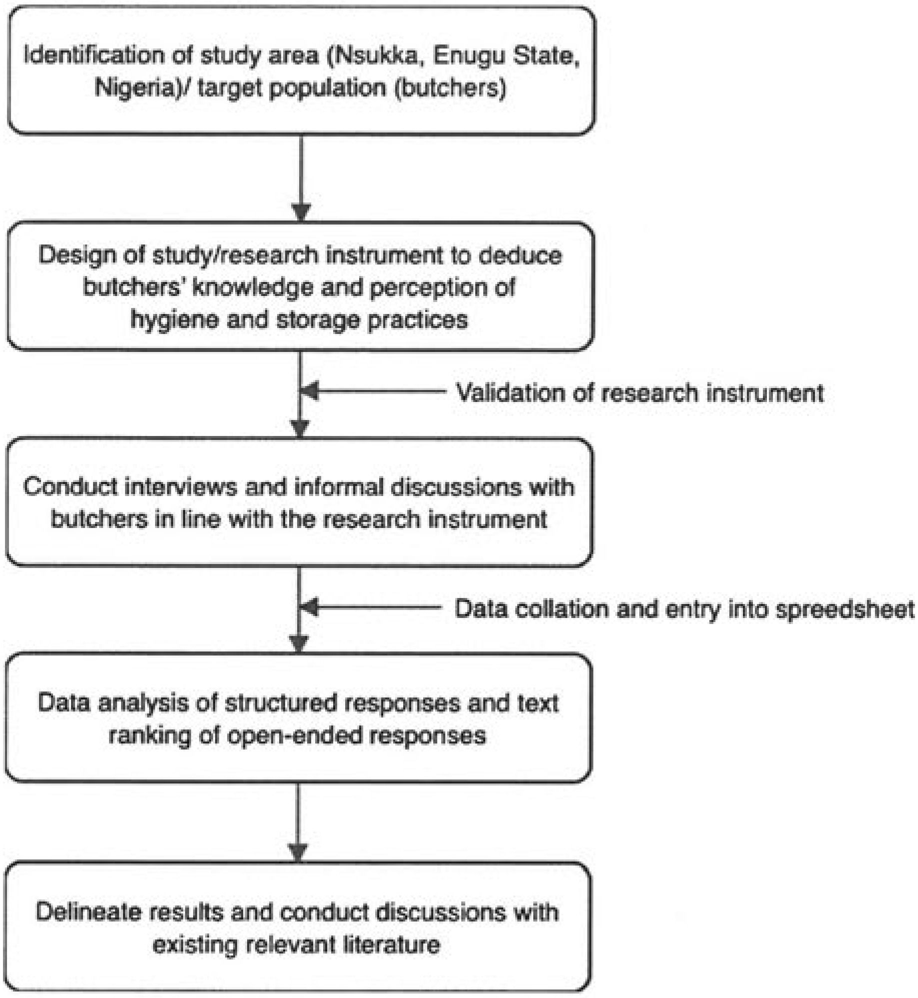

Figure 2. Schematic overview of current study, including the design of questions, conduct of interviews and informal discussions with butchers, data analysis, and delineating the results and discussing them using existing relevant literature.

2.4. Development of Research Instrument

The authors' combined specialist experience/expertise and knowledge together with synthesised relevant literature helped in developing the research instrument, which followed a questionnaire approach. As highly recommended by Taherdoost [22], content validation was applied to ensure the (interview) questions were authentic and reliable. The validation process of the research instrument involved a specialist veterinarian together with a lead butcher, both with combined substantial years of cattle slaughter and slaughterhouse experience. During the content validation process, the questions of the research instrument were critically looked at and amended where deemed necessary, which strengthened the research instrument's relevancy and representation to the targeted research construct/context [22]. The administration of the Butchers Association, represented by the lead butcher, participated in the validation process and subsequent approval of the research instrument (questionnaire). Once approval was obtained, the administration of the questionnaires proceeded.

2.5. Questionnaire Items, Slaughterhouse Workday, and Interview Process

The interview activity, based on questionnaire items, was composed of three sections: (a) demography and self-hygiene; (b) knowledge of good hygiene and storage practices; and (c) perception of good hygiene and storage practices in the slaughterhouse facility.

The questionnaire included a total of 30 questions. Demography and self-hygiene had 6 questions, knowledge of good hygiene and storage practices had 11 questions, and perception of good hygiene and storage practices had 13 questions. A number of these questions required either a 'yes' or 'no' response, with a few others having other categorised responses. Importantly, a number of the questions were open ended, for example, asking 'which' and 'why'. The purpose here was to allow the butchers to provide examples and thoughts where possible. This platform also gave some avenue for some informal discussions. Importantly, the number of questionnaire items were considered not too many. This is because too many items might deter the butchers' participation. In general, the interviews were conducted during slaughterhouse visits and face-to-face with the interviewees, i.e., butchers.

A total of 72 butchers were approached during the survey period. Out of these, questionnaires were administered to a total of 50 butchers, with no butcher participating more than once. This is because a few of them were very occupied at the time and therefore could not participate, whereas a few others were not open to answering the questionnaire. Specifically, the typical slaughterhouse workday involves, among other activities, the cattle being presented for slaughter. The butchers, in addition to humanely handling the slaughtering of cattle and the processing of the carcass, remain actively involved up to the point of sale of the beef and its associated parts. A butcher, with the help of one or more assistants (junior butchers), handles both the slaughtering and the processing of the cattle. The method of cattle slaughter is performed using the transverse cut method. Thereafter, the animal is immobilised and placed in such a way that the head is well restrained before one stroke of a cut across the throat is made with a very sharp knife severing the trachea, oesophagus, and blood vessels. This traditional method allows the animal to be well bled. Besides this, other butchers not directly involved in the actual slaughter activity of a given cattle would be engaged in other slaughterhouse duties, from cleaning the slaughterhouse surroundings to preparing the slaughter slab and its vicinity.

The interview process was conducted by a veterinarian, supported by a trainee veterinarian. The veterinarian is familiar with the slaughterhouse and its personnel. The questionnaire items were administered in such a way to encourage participation. Sampling the butcher to interview was non-random but without any repetition, as carried out by the interviewer. The recruitment process was such that the interviewer approached butchers who were less occupied and engaged with them individually. The open questions provided the butchers the opportunity to freely express themselves, as they shared their thoughts. The interview process was such that the questions were posed to the butchers, and their responses were written down by the interviewer (veterinarian). Through this approach, a relaxed atmosphere was assured, and the interview time was optimised with least-to-no pressure created on the butchers. Given the relaxed atmosphere the interviewer created, the butchers were relaxed, which encouraged and facilitated them to come up with examples where they deemed appropriate.

Each interview started primarily by briefly relaying the objective of the study to the butcher. When this step was achieved, the next step was to conduct the interview by administering the items in the questionnaire to the butcher. Some of the butchers were interviewed while they were working, whereas some had already accomplished their daily tasks prior to the time the interview(s) commenced. In both scenarios, the butchers were able to speak freely and respond to the questions posed to them. The interview process was such that it assured their anonymity and encouraged proactive participation as well as a willingness to provide information in a non-biased, as well as an objective, manner.

To ease the interviewees' understanding of questions especially when (understanding) difficulties arose, the use of the vernacular was applied without any change in both the content and context of the questionnaire items. Essentially, the interview time varied as it was dependent on both the availability and convenience of the interviewees (butchers). In the situation where the interviews could not be accomplished on that day, another time agreed by both parties, i.e., the interviewer and interviewees, was scheduled.

2.6. Statistical Analysis

All data were subject to the Anderson–Darling normality test in which the data fulfilled the assumptions of non-parametric distribution. Therefore, the Kruskal–Wallis analysis of variance (ANOVA) test was applied to establish whether any statistical difference existed between response groups/variables. The results of the analysed data are presented in frequencies, percentages, H-adjusted values, and p-values. Where the correlation was required, Spearman's test was applied; both the correlation coefficient (r) and probability (p) values are reported. The level of statistical significance was set at $p < 0.05$. Minitab Express software (version 1.5.3, Minitab Ltd., Coventry, UK) was used to carry out the statistical analysis. Furthermore, the open-ended responses were then categorised using the word-based technique of Ryan and Bennard [23] with slight modifications. The actual texts, based on the butchers' responses, were sorted in order to arrive at a specific statement/theme, after which the frequency of occurrence was tallied, ranked, and, thereafter, reported in percentages.

3. Results and Discussion

3.1. Demographic and Self-Hygiene of Butchers

The butchers' demographic and self-hygiene statistics, as sampled in the slaughterhouse, are shown in Table 1. At the studied slaughterhouse, the butchers were male ($p < 0.0001$) (Freq. = 100%, $n = 50$), with more of the butchers having primary (Freq. = 50%, $n = 25$) compared to secondary (Freq. = 28%, $n = 14$) education. The male control at the slaughterhouse of this study is consistent with findings reported elsewhere [24–29]. The self-hygiene was assessed based on covering the hair, wearing of an apron, application, and frequency of cleaning the work area. Butchers who covered their hair and wore an apron did not significantly differ ($p > 0.05$) from those who did not. Butchers who applied only water (Freq. = 66%, $n = 33$) compared to water and soap (Freq. = 32%, $n = 16$) to clean the work area/space of the beef slaughter activity differed significantly ($p < 0.0001$), similar to the cleaning frequency of before and after (Freq. = 88%, $n = 44$) compared to now and then (Freq. = 10%, $n = 5$) (Table 1). Notwithstanding their inconsistencies in the use of the apron, the butchers appeared undeterred in their consciousness of their self-hygiene as well as in the frequency of cleaning their work area. Essentially, the butchers' demographic and self-hygiene statistics are relevant because they reveal some very key fundamentals, such as the butchers' level of education, how the butchers appear at the slaughterhouse workday specific to the context of hygiene, how they keep their slaughterhouse work area tidy, and how frequently they perform cleaning activities.

Table 1. Butchers' demographic and self-hygiene statistics, as sampled in the slaughterhouse.

Item	Sub-Item	Frequency % (n = 50)	H-adj.	*p*-Value
Gender	Male Female	100% ($n = 50$) 0% ($n = 0$)	99.00	<0.0001
Education status	Primary Secondary Tertiary Unknown	50% ($n = 25$) 28% ($n = 14$) 16% ($n = 8$) 6% ($n = 3$)	13.73	<0.0010
Hair of butcher	Covered Uncovered Unknown	44% ($n = 22$) 44% ($n = 22$) 12% ($n = 6$)	-	>0.05
Wearing an apron	Used Not used Unknown	48% ($n = 24$) 42% ($n = 21$) 10% ($n = 5$)	-	>0.05
Application of cleaning the work area	Water Water+soap Water+soap+disinfectant	66% ($n = 33$) 32% ($n = 16$) 2% ($n = 1$)	45.83	<0.0001
Frequency of cleaning the work area	Before and after each activity Now and then Unknown	88% ($n = 44$) 10% ($n = 5$) 2% ($n = 1$)	60.26	<0.0001

3.2. Butchers' Knowledge of Good Hygiene and Storage Practices

Knowledge is said to accumulate through learning processes, which may come either by formal or informal education, together with personal experience as well as experiential sharing [30]. The statistics of butchers' knowledge of good hygiene and storage practices are shown in Table 2. Butchers were strongly ($p < 0.0001$) familiar with good hygiene (Freq. = 96%, n = 48) and storage (Freq. = 98%, n = 49) practices. Largely, they had acquired the knowledge informally (Freq. = 88%, n = 44) and possessed >5 years of experience in the beef-processing sector (Freq. = 82%, n = 41). Butchers acquiring their knowledge of good hygiene and storage practices informally demonstrates the relevance of their apprenticeship style of (good hygiene and storage practice) training. Indeed, such an apprenticeship style, typically in an in-house setting, can still be considered as an essential professional package, wherein experiential knowledge and practice is transferred from a certified butcher to a learner/trainee during the slaughterhouse workday activities and remains continuous over a period of time. Moreover, the butchers herein provided some examples of good hygiene practices employed in the slaughterhouse, which ranked as follows: use of clean water and (antiseptic) soap to wash hands (Freq. = 54%, n = 27) >use of disinfectant, clean water, and brush to scrub workspace floor (Freq. = 42%, n = 21) >use of clean water to wash the fresh meat (Freq. = 34%, n = 17) >regular washing of knives, wearing an apron, and washing of other work instruments (Freq. = 24%, n = 12) >regular washing of tables/slabs where the meat is split and prepared for market (Freq. = 22%, n = 11) >covering fresh meat (from flies) after washing and during refrigeration and transportation (Freq. = 10%, n = 5) >sweeping out debris/dirt off slaughter areas and burning the debris/dirt (Freq. = 4%, n = 2).

Table 2. Statistics of butchers' responses regarding their knowledge of good hygiene and storage practices.

No.	Question	Response	Frequency % (n = 50)	H-adj	p-Value
1	Are you familiar with good hygiene practices?	Yes No	96% (n = 48) 4% (n = 2)	83.79	<0.0001
2	Are you familiar with good storage practices?	Yes No	98% (n = 49) 0% (n = 0)	95.12	<0.0001
3	If yes to 1/2, how did you acquire the hygiene and or storage practice knowledge?	Formal Informal	6% (n = 3) 88% (n = 44)	66.81	<0.0001
4	Years of experience in the beef-processing sector	<1 year 1–5 years >5 years	0% (n = 0) 14% (n = 7) 82% (n = 41)	87.83	<0.0001
5	Did you have prior hygiene/storage knowledge/experience before engaging in the slaughterhouse?	Yes No	20% (n = 10) 76% (n = 38)	31.10	<0.0001
6	Do you know any foodborne pathogen associated with beef?	Yes No	8% (n = 4) 90% (n = 45)	66.59	<0.0001
7	Do you know the importance of hand washing?	Yes No	96% (n = 48) 0% (n = 0)	91.38	<0.0001
8	Do you know how to use the storage facilities in the slaughterhouse?	Yes No	96% (n = 48) 0% (n = 0)	91.38	<0.0001

From the conducted interviews herein, we opine that the butchers certainly have the concept of hygiene in their minds, and do think about it, despite the challenges they are confronted with during their slaughterhouse activities. Obviously, the knowledge of hygiene in butchers grows and eventually matures through their work experience over time. Additionally, the degree of hygiene knowledge would differ from butcher to butcher, even within the same slaughterhouse workplace. Probably in some of the more experienced butchers, the degree of hygiene knowledge exemplified during slaughterhouse activities would be higher than the less experienced ones. Despite the routine nature of the butchers' work every day, there would likely be something new to learn, now and then. According to the World Health Organization (WHO) of the United Nations, the simple act of washing hands with soap and water reduces the incidence of diarrhoea caused by foodborne pathogens by up to 35% [30]. Most certainly, these routine cattle slaughter procedures and their associated activities, carried out over a period of time, help in consolidating butchers' understanding of good hygiene practices in the slaughterhouse. The high perishable nature of meat makes the butchers' knowledge level, particularly with respect to hygiene within the meat industry, very essential to ensure consumer health and safety [31].

Further, the butchers provided some examples of good storage practices obtained within the slaughterhouse, which ranked as follows: use of cold room (Freq. = 56%, $n = 28$) > use of (private) refrigerator/freezer (Freq. = 36%, $n = 18$), as shown in Table 2. Significantly fewer butchers ($p < 0.0001$) indicated prior hygiene and storage knowledge/experience before engaging in the slaughterhouse (Freq. = 20%, $n = 10$) and were able to name a foodborne pathogen associated with beef (Freq. = 8%, $n = 4$). The few butchers able to name a foodborne pathogen associated with beef could only provide the example of *Salmonella* (Freq. = 8%, $n = 4$). Despite this, significantly more butchers ($p < 0.0001$), also shown in Table 2, indicated knowing the importance of hand sanitisation and how to use the storage facilities in the slaughterhouse (Freq. = 96%, $n = 48$). Essentially, the inability of butchers to name a foodborne pathogen might not necessarily deter their commitment and diligence to duty or their capacity to connect effectively with good hygiene and storage practices. Moreover, the ranking of butchers' responses to examples with respect to the knowledge aspects may well depict the differences in (their) emphasis on good hygiene and storage practices. Based on these knowledge aspects, the butchers have a responsibility to continually improve on the slaughterhouse services they render to the public.

3.3. Butchers' Perception of Good Hygiene and Storage Practices

The statistics of butchers' perception of good hygiene and storage practices are shown in Table 3. Butchers significantly ($p < 0.0001$) perceived both good hygiene and storage practices as very important (Freq. = 72%, $n = 36$). Despite this, a fair number, respectively, perceived the hygiene and storage level of the slaughterhouse facility as 'not so high' (Freq. = 48%, $n = 24$) and 'very high' (Freq. = 58%, $n = 29$). The response of 'not so high' might have arisen from butchers' experience regarding hygiene challenges encountered in the slaughterhouse. When asked why good hygiene storage practices were important, butchers openly responded: 'to prevent meat contamination/spoilage and foodborne disease spread' (Freq. = 42%, $n = 21$) of equal response with 'to maintain clean/disease-free beef that ensures public health and consumer safety' (Freq. = 42%, $n = 21$), with 'to promote butchers' self-hygiene' (Freq. = 6%, $n = 3$) as the least mentioned. In the beef industry/production, butchers remain among the critical stakeholders. This is because of the linkage butchers provide between potential zoonotic disease and the meat-processing chain, particularly at slaughterhouses [13].

The majority of butchers significantly agreed ($p < 0.0001$) that aspects of the hygiene and storage facilities of the slaughterhouse required improvement (Freq. = 90%, $n = 45$) and that the local, state, as well as federal governments had a role to play to enhance the slaughterhouse hygiene and storage facilities/practices (Freq. = 84%, $n = 42$) (Table 3). Indeed, inadequate storage practices (as well as facilities) are among the key challenges that confront the meat industry [1,3,6,16]. Moreover, the butchers herein also provided examples of the slaughterhouse hygiene/storage aspects that needed improvement, which ranked as follows: improving the water supply (Freq. = 28%, $n = 14$) > improving the conditions of the slaughter slab and vicinity (Freq. = 22%, $n = 11$) > improving the (waste) drainage system (Freq. = 16%, $n = 8$) > improving the electricity supply (Freq. = 14%, $n = 7$) > improving the refrigeration cold-room/freezing facilities (Freq. = 10%, $n = 5$) > provision of (more) beef-processing rooms (Freq. = 8%, $n = 4$). When asked which of either hygiene or storage practices presented a greater challenge, more butchers indicated 'hygiene' (Freq. = 58%, $n = 29$) over 'storage' (Freq. = 16%, $n = 8$). Clearly, within the slaughterhouse, the butchers encounter more challenges of hygiene compared with those of storage. When asked which among the local, state, and federal governments had a role to play to enhance the slaughterhouse hygiene and storage facilities/practices, a reasonable proportion of butchers indicated 'local' (Freq. = 74%, $n = 37$), much less the 'state' (Freq. = 8%, $n = 4$), with no mention of the 'federal' government (Freq. = 0%, $n = 0$).

Table 3. Statistics of butchers' responses regarding their perception of good hygiene and storage practices.

No.	Question	Response	Frequency ($n = 50$)	H-adj	*p*-Value
1	As a butcher, how do you perceive good hygiene/storage practice, in general?	Very important	72% ($n = 36$)	58.88	<0.0001
		Important	28% ($n = 14$)		
		Not sure	0% ($n = 0$)		
2	How do you perceive the hygiene level at the slaughterhouse facility?	Very high	12% ($n = 6$)	37.04	<0.0001
		High	38% ($n = 19$)		
		Not so high	48% ($n = 24$)		
		Not sure	2% ($n = 1$)		
3	How do you perceive the storage level at the slaughterhouse facility?	Very high	58% ($n = 29$)	61.66	<0.0001
		High	38% ($n = 19$)		
		Not so high	4% ($n = 2$)		
		Not sure	0% ($n = 0$)		
4	Are there some aspects of hygiene and storage at the slaughterhouse you believe require improvement?	Yes	90% ($n = 45$)	63.66	<0.0001
		No	10% ($n = 5$)		
5	Do you believe the local, state, and federal governments have a role to play to enhance the slaughterhouse hygiene and storage facilities/practices?	Yes	84% ($n = 42$)	45.78	<0.0001
		No	16% ($n = 8$)		
6	Do you believe the government regulation protects slaughterhouse good hygiene and storage practices?	Yes	52% ($n = 26$)	-	>0.05
		No	48% ($n = 24$)		
7	Do you believe the above (6) has helped to sustain slaughterhouse hygiene and storage facilities?	Yes	52% ($n = 26$)	-	>0.05
		No	48% ($n = 24$)		

With regard to government regulation, there was no statistical difference ($p > 0.05$) between those who believed and did not believe that the government regulation protects the slaughterhouse good hygiene and storage practices. In addition, there was no statistical difference ($p > 0.05$) between those who believed and did not believe that the government regulation helps to sustain the (slaughterhouse) facilities. Further, when asked about how government regulation helps to sustain the slaughterhouse facilities, the butchers' open responses ranked as follows: monthly participation in the environmental clean-up of the vicinity (Freq. = 32%, $n = 16$) > some regulatory hygiene control of slaughtered beef production (Freq. = 12%, $n = 6$) > regulatory standard of butchers' conduct (by LGA and Butchers Association) (Freq. = 10%, $n = 5$). There is a high chance that butchers would more likely associate with the local government and its own local association and cooperate effectively with the instituted (slaughterhouse) regulation. There is the need, therefore, for the government to rise up to their expected role in the slaughterhouse, particularly to increase hygiene levels, in order to enhance the butchers' protection and safety. In addition, the butchers consider good hygiene and storage practices as an obligation as well as responsibility for the public good.

3.4. Correlation Outcomes of Knowledge and Perception Aspects

The correlation analysis between knowledge and perception aspects was conducted with respect to butchers' responses to good hygiene and storage practices. Specifically, the correlation coefficients, respectively, obtained between highly responded butchers' knowledge, perception, and knowledge and perception aspects of good hygiene and storage practices are shown in Tables 4–6. For the knowledge aspects, there were positive correlations between the familiarity of good storage practices and having more than 5 years of work experience in the beef-processing sector ($r = 0.3049$, $p = 0.0313$) as well as knowing the importance of hand washing and how to use the slaughterhouse storage facilities ($r = 1.0000$, $p < 0.0001$) (Table 4). The meat safety knowledge of butchers increased with their years of professional work experience [30]. On the other hand, the perception of good hygiene and storage practices being very important correlated positively with the perception of the hygiene level of the slaughterhouse being not so high ($r = 0.5100$, $p = 0.0002$), the (slaughterhouse) storage level being very high ($r = 0.6426$, $p < 0.0001$), the belief that the local, state, and/or federal governments had a role to play to enhance the (slaughterhouse) hygiene and storage facilities/practices ($r = 0.4569$, $p = 0.0009$), the belief that the government regulation protects the (slaughterhouse) good hygiene and storage practices ($r = 0.5599$, $p < 0.0001$), and the belief that the government regulation can help sustain the (slaughterhouse) hygiene and storage facilities ($r = 0.5345$, $p < 0.0001$) (Table 5).

Table 4. Correlation coefficients obtained between highly responded knowledge aspects of good hygiene and storage practices of butchers.

Variable	A1	A2	A3	A4	A5	A6	A7
A2	−0.0292 [1] 0.8407 [2]						
A3	0.2387 0.0950	−0.0528 0.7160					
A4	−0.0956 0.5088	0.3049 0.0313 *	−0.1730 0.2295				
A5	0.1243 0.3899	−0.0803 0.5794	0.2248 0.1165	−0.1414 0.3274			
A6	0.2722 0.0559	−0.0476 0.7426	−0.1231 0.3944	−0.1562 0.2788	0.1249 0.3875		
A7	−0.0417 0.7739	−0.0292 0.8407	0.2387 0.0950	−0.0956 0.5088	0.1243 0.3899	0.2722 0.0559	
A8	−0.0417 0.7739	−0.0292 0.8407	0.2387 0.0950	−0.0956 0.5088	0.1243 0.3899	0.2722 0.0559	1.0000 <0.0001 *

[1] Correlation coefficient; [2] Probability level; * Correlation data (also presented in italics) are significantly different at $p < 0.05$; Variable details: A1 = indicated 'yes' to familiar with good hygiene practices; A2 = indicated 'yes' to familiar with good storage practices; A3 = informally acquired good hygiene and storage practices; A4 = more than 5 years of slaughterhouse experience; A5 = indicated 'no' to prior knowledge/experience before joining the slaughterhouse; A6 = indicated 'no' to knowing any foodborne pathogen associated with beef; A7 = indicated 'yes' to knowing the importance of hand washing; A8 = indicated 'yes' on how to use the storage facilities in the slaughterhouse.

Table 5. Correlation coefficients obtained between highly responded perception aspects of good hygiene and storage practices of butchers.

Variable	B1	B2	B3	B4	B5	B6	B7
B2	0.5100 [1] 0.0002 * [2]						
B3	0.6426 <0.0001 *	0.5743 <0.0001 *					
B4	0.2376 0.0967	0.3203 0.0234 *	0.1216 0.4004				
B5	0.4569 0.0009 *	0.4193 0.0024 *	0.1813 0.2077	0.4001 0.0040 *			
B6	0.5599 <0.0001 *	0.8430 <0.0001 *	0.7235 <0.0001 *	0.3469 0.0136 *	0.3451 0.0141 *		
B7	0.5345 <0.0001 *	0.8006 <0.0001 *	0.6889 <0.0001 *	0.3333 0.0180 *	0.3273 0.0203 *	0.9608 <0.0001 *	

[1] Correlation coefficient; [2] Probability level; * Correlation data presented in italics are significantly different at $p < 0.05$; Variable details: B1 = indicated 'very important' for how do you perceive good hygiene/storage practice, in general; B2 = indicated 'not so high' for how do you perceive the hygiene level at the slaughterhouse facility; B3 = indicated 'very high' for how do you perceive the storage level at the slaughterhouse facility; B4 = indicated 'yes' to are there aspects of hygiene and storage at the slaughterhouse you believe require improvement; B5 = indicated 'yes' to do you believe the local, state, and federal governments have a role to play to enhance the slaughterhouse hygiene and storage facilities/practices; B6 = indicated 'yes' to do you believe the government regulation protects slaughterhouse good hygiene and storage practices; B7 = indicated 'yes' to do you believe the above (6) has helped to sustain slaughterhouse hygiene and storage facilities.

Table 6. Correlation coefficients obtained between highly responded knowledge and perception aspects of good hygiene and storage practices of butchers.

Variable	B1	B2	B3	B4	B5	B6	B7
A1	0.1000 [1] 0.4895 [2]	0.1961 0.1723	0.0331 0.8196	0.2722 0.0559	0.1893 0.1879	0.2125 0.1385	0.2041 0.1551
A2	−0.0891 0.5384	−0.1487 0.3028	−0.1216 0.4004	−0.0476 0.7426	−0.0624 0.6671	−0.1373 0.3419	−0.1429 0.3223
A3	0.0439 0.7623	−0.0148 0.9188	0.1846 0.1995	0.0821 0.5710	0.1746 0.2252	0.0148 0.9188	0.0000 1.0000
A4	−0.2922 0.0395 *	−0.4877 0.0003 *	−0.3987 0.0041 *	−0.1562 0.2788	−0.2045 0.1543	−0.4501 0.0010 *	−0.3644 0.0093 *
A5	−0.1418 0.3258	−0.0225 0.8768	−0.0987 0.4954	0.1249 0.3875	−0.1175 0.4163	−0.1650 0.2523	−0.1873 0.1927
A6	−0.0594 0.6820	0.1868 0.1939	−0.0135 0.9258	0.1111 0.4424	0.0364 0.8020	0.2135 0.1366	0.2000 0.1638
A7	*0.3273* *0.0203* *	0.1961 0.1723	0.2399 0.0934	−0.0680 0.6387	0.1893 0.1879	0.2125 0.1385	0.2041 0.1551
A8	*0.3273* *0.0203* *	0.1961 0.1723	0.2399 0.0934	−0.0680 0.6387	0.1893 0.1879	0.2125 0.1385	0.2041 0.1551

[1] Correlation coefficient; [2] Probability level; *Correlation data (also presented in italics) are significantly different at $p < 0.05$; Variable details: A1 = indicated 'yes' to familiar with good hygiene practices; A2 = indicated 'yes' to familiar with good storage practices; A3 = informally acquired good hygiene and storage practices; A4 = more than 5 years of slaughterhouse experience; A5 = indicated 'no' to prior knowledge/experience before joining the slaughterhouse; A6 = indicated 'no' to knowing any foodborne pathogen associated with beef; A7 = indicated 'yes' to knowing the importance of hand washing; A8 = indicated 'yes' on how to use the storage facilities in the slaughterhouse; B1 = indicated 'very important' for how do you perceive good hygiene/storage practice, in general; B2 = indicated 'not so high' for how do you perceive the hygiene level at the slaughterhouse facility; B3 = indicated 'very high' to how do you perceive the storage level at the slaughterhouse facility; B4 = indicated 'yes' to are there aspects of hygiene and storage at the slaughterhouse you believe require improvement; B5 = indicated 'yes' to do you believe the local, state, and federal governments have a role to play to enhance the slaughterhouse hygiene and storage facilities/practices; B6 = indicated 'yes' to do you believe the government regulation protects slaughterhouse good hygiene and storage practices; B7 = indicated 'yes' to do you believe the above (6) has helped to sustain slaughterhouse hygiene and storage facilities.

The perception of the hygiene level of the slaughterhouse being 'not so high' correlated positively with the (slaughterhouse) storage level being 'very high' ($r = 0.5743$, $p < 0.0001$), the agreement that some aspects of hygiene and storage facilities needed improvement ($r = 0.3203$, $p = 0.0234$), the belief that the local, state, and/or federal governments had a role to play in enhancing the (slaughterhouse) hygiene and storage facilities/practices ($r = 0.4193$, $p = 0.0024$), the belief that the government regulation protects the (slaughterhouse) good hygiene and storage practices ($r = 0.8430$, $p < 0.0001$), and the belief that the government regulation could help sustain the (slaughterhouse) hygiene and storage facilities ($r = 0.8006$, $p < 0.0001$). The perception of the slaughterhouse storage level being 'very high' correlated positively with the belief that the government regulation protects (slaughterhouse) good hygiene and storage practices ($r = 0.7235$, $p < 0.0001$) and the belief that the government regulation could help to sustain (slaughterhouse) hygiene and storage facilities ($r = 0.6889$, $p < 0.0001$) (Table 5).

The agreement that some aspects of the hygiene and storage facilities needed improvement correlated positively with the belief that local, state, and/or federal governments had a role to play to enhance (slaughterhouse) hygiene and storage facilities/practices ($r = 0.4001$, $p = 0.0040$), the belief that the government regulation protects (slaughterhouse) good hygiene and storage practices ($r = 0.3469$, $p = 0.0136$), and the belief that the government regulation helps to sustain (slaughterhouse) hygiene and storage facilities ($r = 0.3333$, $p = 0.0180$). The belief that local, state, and/or federal governments had a role to play to enhance (slaughterhouse) hygiene and storage facilities/practices correlated positively with the belief that the government regulation protects (slaughterhouse) good hygiene and storage practices ($r = 0.3451$, $p = 0.0141$) and the belief that the government regulation helps to sustain (slaughterhouse) hygiene and storage facilities ($r = 0.3273$, $p = 0.0203$). The belief that the government regulation protects (slaughterhouse) good hygiene and storage practices correlated positively with the belief that the government regulation helps to sustain (slaughterhouse) hygiene and storage facilities ($r = 0.9608$, $p < 0.0001$) (Table 5). Clearly, the above-mentioned correlations suggest that butchers' knowledge and perception of good hygiene and storage aspects can interact when considered in the practice point of view. In addition, the butchers herein to some degree appear very mindful of their knowledge and perception of good hygiene and storage practices within the slaughterhouse.

For the knowledge versus perception aspects, both negative and positive significant correlations were obtained. The possession of more than five years of work experience in the slaughterhouse correlated negatively with the perception of good hygiene and storage practices being 'very important' ($r = -0.2922$, $p = 0.0395$), the perception of the (slaughterhouse) hygiene level being 'not so high' ($r = -0.4877$, $p = 0.0003$), the perception of the (slaughterhouse) storage level being 'very high' ($r = -0.3987$, $p = 0.0041$), the belief that the government regulation protects (slaughterhouse) good hygiene and storage practices ($r = -0.4501$, $p = 0.0010$), and the belief that the government regulation helps to sustain (slaughterhouse) hygiene and storage facilities ($r = -0.3644$, $p = 0.0093$). On the other hand, the perception of good hygiene and storage practices being 'very important' correlated positively with knowing the importance of hand washing ($r = 0.3273$, $p = 0.0203$) as well as knowing how to use the slaughterhouse storage facilities ($r = 0.3273$, $p = 0.0203$) (Table 6). The negative correlation suggests that the greater the number of years of work experience at the slaughterhouse may not in every respect reflect the degree to which the butchers perceive the following: (a) how they see their good hygiene and storage practices in general; (b) how they see the (slaughterhouse) hygiene and storage levels; (c) how they see the capacity of government regulation to protect (slaughterhouse) good hygiene and storage practices; and (d) how they see the government regulation to help sustain (slaughterhouse) hygiene and storage facilities. Overall, the perception of good hygiene and storage practices appears to be correlated more, compared to knowledge and knowledge versus perception aspects. This might suggest that the butchers are able to reveal their knowledge of good hygiene and storage practices via perception. This is probably by the internalisation of the information gathered from daily routine activities that directly involve good hygiene and storage practices. Noteworthily, it might be neither too difficult nor take too much time for the butchers to implement the connection between the actual and theoretical knowledge of good hygiene and storage practices. The actual aspect, in this case, specifically refers to what the butchers were able to reveal about their knowledge of good hygiene and storage practices. The theoretical aspect, in this case, cumulates all scientific literature within the body of knowledge specific to good hygiene and storage practices.

4. Limitations

This current work involved a total number of 50 butchers within a specific slaughterhouse. This might be considered a limitation to this study because more butchers involving a number of slaughterhouses would most likely increase the study's representativeness and robustness. Additionally, the nature of the sampling, which was non-random, could also be perceived as a limitation. The non-random sampling approach was selected given that butchers in only one slaughterhouse were being studied. Random sampling will be more applicable where a number of slaughterhouses are to be investigated. Even though we believe that the non-random sampling used in this study would not necessarily increase the bias, given that each butcher will share their own particular work experience, random sampling would definitely play a role to further reduce the bias. A perceived limitation could also be the 'yes' or 'no' answers given by the butchers in response to some specific questions, which might not necessarily reveal the truth. Additionally, the attributes of knowledge and perception studied herein might be perceived as somewhat preliminary, which could be perceived as another limitation. However, we believe the current study lays a foundation for more robust studies in the future.

5. Conclusions

The butchers at the slaughterhouse were male, acquired their knowledge informally, and had, largely, >5 years of slaughterhouse experience. The majority of the butchers considered both good hygiene and storage practices as an obligation and responsibility for the public good. They equally agreed that there were aspects of the hygiene and storage facilities at the slaughterhouse that required improvement. They were able to provide examples that exemplified their knowledge and perception aspects of good hygiene and storage practices as employed within the slaughterhouse activities. Correlation coefficients were obtained between the highly responded knowledge, perception, and knowledge and perception aspects of good hygiene and storage practices. The perception aspects correlated a lot more, compared to knowledge as well as knowledge versus perception.

Very conscious of their knowledge and perception of good hygiene and storage practices, the butchers herein have to continually improve the slaughterhouse services to ensure beef quality and consumer safety. There is a need for the local, state, and federal governments to get more involved, in particular, to enhance the butchers' hygiene and storage practices, as well as to improve the slaughterhouse facilities. In this context, this work has made an attempt to address an aspect of Nigerian butchers' occupation that directly leads to enhancing livestock welfare and product health and safety. The reasons for assessing butchers' knowledge and perception with respect to hygiene include finding out areas where they require support and understanding the general level of their hygiene knowledge, as well as how they perceive hygiene in the context of their slaughterhouse activities. Through this understanding, it would be possible to decipher the areas where butchers' hygiene challenges emanate from and where the local, state, and federal governments, together with stakeholders, could step in in order to serve as a support system to help formulate problem-solving strategies for the cattle/meat industry.

Overall, this current study lays the foundation for a call for future government-funded nationwide campaigns in Nigeria, which would help enhance the meat industry regulatory standards specific to good hygiene and storage competencies and the status of butchers and slaughterhouses. As many of the butchers had more than five years of slaughterhouse experience, future work could aim to deduce how the frequent usage of various cleaning facilities and procedures associates with their length/years of work experience. Another future study could be to identify the risk factors for poor hygiene or the 'positive factors' for good hygiene and corresponding responses to the other explanatory variables, and this can be achieved using logistic regression analysis. Another direction of future work should be to look at the function and role of HACCP in a typical slaughterhouse, particularly in the Nigerian context.

Author Contributions: Conceptualisation, C.O.R.O.; Data curation, C.O.R.O.; Formal analysis, C.O.R.O.; Funding acquisition, C.O.R.O. and M.K.; Investigation, C.O.R.O., O.C.N., and M.K.; Methodology, C.O.R.O.; Project administration, C.O.R.O., O.C.N., and M.K.; Software, C.O.R.O. and O.C.N.; Validation, O.C.N. and M.K.; Visualisation, C.O.R.O., O.C.N., and M.K.; Writing—original draft, C.O.R.O.; Writing—review and editing, C.O.R.O., O.C.N., and M.K. All authors have read and agreed to the published version of the manuscript.

Funding: The publication was financed by the project UPWR 2.0: International and Interdisciplinary Programme of Development of Wrocław University of Environmental and Life Sciences, co-financed by the European Social Fund under the operational programme Knowledge Education Development, under contract no. POWR.03.05.00-00-Z062/18 of 4 June 2019.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: Authors C.O.R.O. and M.K. appreciate the funding support from Wrocław University of Environmental and Life Sciences, Poland. This work was supported by Wrocław University of Environmental and Life Sciences (Poland) under the Ph.D. research programme 'Doctoral student grant at the Doctoral School of Wrocław University of Life Sciences' no: N020/0011/20.

Conflicts of Interest: The authors have declared no conflict of interest.

References

1. Smith, S.B.; Gotoh, T.; Greenwood, P.L. Current situation and future prospects of global beef production: Overview of special issue. *Asian-Australas. J. Anim. Sci.* **2018**, *31*, 927–932. [CrossRef] [PubMed]
2. Tano, K.; Kamuanga, M.; Faminow, M.D.; Swallow, B. Using conjoint analysis to estimate farmer's preferences for cattle traits in West Africa. *Ecol. Econ.* **2003**, *45*, 393–407. [CrossRef]
3. Tewe, O.O. *Sustainability and Development: Paradigms from Nigeria's Livestock Industry*; An Inaugural Lecture delivered at the University of Ibadan, Nigeria; Ibadan University Press: Ibadan, Nigeria, 1997; p. 45. ISBN 978-121-3159.
4. Lawal-Adebowale, O.A. Dynamics of ruminant livestock management in the context of the nigerian agricultural system. In *Livestock Production*; Javed, K., Ed.; Intech Open Limited: London, UK, 2012. [CrossRef]
5. Ogbeide, O.A. Meat Industry Development in Nigeria: Implications of the Consumers Perception. *Mayfair J. Agribus. Manag.* **2015**, *1*, 59–75.
6. Tambi, E.N.; Maina, O.W. Patterns of change in beef production and consumption in Africa. *Rev. Sci. Tech. (Int. Off. Epizoot.)* **2003**, *22*, 965–976. [CrossRef] [PubMed]
7. Tambi, E.N.; Maina, O.W.; Bessin, R. Animal and Animal Products Trade in Africa: New Development Perspectives in International Trade for Africa. *J. Int. Food Agricbusiness Mark.* **2003**, *14*, 49–67. [CrossRef]
8. Aniebo, A.O.; Njike, M.C.; Okoli, I.C. Notes on abattoir operations at Afor Ajala Mbaise, Imo State, Nigeria. *Anim. Prod. Res. Adv.* **2008**, *4*, 222–226. [CrossRef]
9. Nwankwo, I.O.; Onunkwo, J.I.; Ogugua, A.J.; Ezugwu, R.N. Gross pathological conditions in eviscerated organs of cattle in nsukka Slaughter Slab, Enugu State: The economic and public health implications. *Niger. J. Anim. Prod.* **2019**, *46*, 40–45.
10. Food Guidelines, National Agency for Food & Drug Administration & Control (NAFDAC). Available online: www.nafdac.gov.ng/food/food-guidelines/ (accessed on 13 June 2020).
11. Federal Ministry of Health. National Policy on Food Safety and its Implementation Strategy, 2014, Federal Ministry of Health, Abuja, Nigeria. Available online: http://extwprlegs1.fao.org/docs/pdf/nig151436.pdf (accessed on 2 July 2020).
12. Bersisa, A.; Tulu, D.; Negera, C. Investigation of bacteriological quality of meat from abattoir and butcher shops in Bishoftu, Central Ethiopia. *Int. J. Microbiol.* **2019**, *2019*, 6416803. [CrossRef]
13. Prabhakar, Z.N.; Lokesh, M.; Saidaiah, M.; Sai, E.S. Awareness regarding zoonotic diseases among the butchers of Proddatur, Kadapa Dist., AP, India. *Iran. J. HealthSaf. Environ.* **2017**, *4*, 729–737.
14. Ababio, P.F.; Taylor, K.D.A.; Swainson, M.; Daramola, B.A. Effect of good hygiene practices intervention on food safety in senior secondary schools in Ghana. *Food Control* **2016**, *6*, 18–24. [CrossRef]
15. Raspor, P.; Ambrožič, M.; Jevšnik, M. Food chain safety management systems: The impact of good practices. In *Advances in Food Process Engineering Research and Applications*; Yanniotis, S., Taoukis, P., Stoforos, N.G., Karathanos, V.T., Eds.; Food Engineering Series; Springer: Boston, MA, USA, 2013; p. 19. [CrossRef]
16. Good Storage Practices. Available online: https://minpharmum.files.wordpress.com/2011/09/gsp.pdf (accessed on 17 May 2020).
17. Selmat, J.; Iqbal, S.Z. (Eds.) *Food Safety: Basic Concepts, Recent Issues and Future Challenges*; Springer International Publishing: Cham, Switzerland, 2016; p. 164. ISBN 978-3-319-39253-0.
18. Raspor, P.; Jevšnik, M. Good nutritional practice from producer to consumer. *Crit. Rev. Food Sci. Nutr.* **2008**, *48*, 276–292. [CrossRef]
19. Varzakas, T.; Tzia, C. *Handbook of Food Processing, Food Safety, Quality and Manufacturing Processes*; CRC Press: Boca Raton, FL, USA, 2016; p. 676. ISBN 978-1-4987-2178-3.
20. World Medical Association (WMA). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *J. Am. Med Assoc.* **2013**, *310*, 2191–2194. [CrossRef] [PubMed]
21. Nwanta, J.A.; Onunkwo, J.; Ezenduka, E. Analysis of Nsukka Metropolitan Abattoir Solid Waste and its Bacterial Contents in South Eastern Nigeria: Public Health Implication. *Arch. Environ. Occup. Health* **2010**, *65*, 21–26. [CrossRef] [PubMed]
22. Taherdoost, H. Validity and Reliability of the Research Instrument: How to Test the Validation of a Questionnaire/Survey in a Research. *Int. J. Acad. Res. Manag.* **2016**, *5*, 28–36. [CrossRef]
23. Ryan, G.W.; Bernard, H.R. Techniques to Identify Themes. *Field Methods* **2003**, *15*, 85–109. [CrossRef]
24. Adzitey, F.; Abu, A.; Teye, G.A.; Weyire, A.; Evans, A.I.; Boateng, F. Handling and storage of leftover meat by butchers in the Tamale metropolis and Bolgatanga municipality of Ghana. *J. Meat Sci. Technol.* **2018**, *6*, 30–35.
25. Asuming-Bediako, N.; Aikins-Wilson, S.; Affedzie-Obresi, S.; Adu, E.K. Challenges in the Butchery Industry: Potential Opportunities for Business in Ghana. *Ghana J. Agric. Sci.* **2018**, *52*, 121–129.
26. Simpson, R.; Slutskaya, N.; Hughes, J. Emotional dimensions of dirty work: Men's encounter with taint in the butcher trade. *Int. J. Work Organ. Emot.* **2011**, *4*, 195–212. [CrossRef]
27. Simpson, R.; Hughes, J.; Slutskaya, N.; Balta, M. Sacrifice and distinction in dirty work: Men's construction of meaning in the butcher trade. *Work Employ. Soc.* **2014**, *28*, 754–770. [CrossRef]
28. Voracek, M.; Gabler, D.; Kreutzer, C.; Stieger, S.; Swami, V.; Formann, A.K. Multi-method personality assessment of butchers and hunters: Beliefs and reality. *Personal. Individ. Differ.* **2010**, *49*, 819–822. [CrossRef]

29. Elblla, M.E.E.A. Assessment of Meat Safety Knowledge, Attitudes and Practices among the Slaughterhouse Workers in Ed Dueim City-White Nile State. Master of Preventive Veterinary Medicine Thesis, College of Graduate Studies, Sudan University of Science and Technology, Khartoum, Sudan, 2018; p. 44.
30. Jianu, C.; Golet, I. Knowledge of food safety and hygiene and personal hygiene practices among meat handlers operating in western Romania. *Food Control* **2014**, *42*, 214–219. [CrossRef]
31. Metaxopoulos, J.; Kritikos, D.; Drosinos, E.N. Examination of microbiological parameters relevant to the implementation of GHP and HACCP system in Greek meat industry in the production of cooked sausages and cooked cured meat products. *Food Control* **2003**, *14*, 323–332. [CrossRef]

04 czerwca 2023 r

(miejscowość i data)

Charles Odilichukwu R. OKPALA...

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy ...... *Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021). Assessing Nigerian Butchers 'Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. Foods, 10(6), 1165.*.... mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

Okpala

04 June 2023..............

data i podpis

…DVM MSc Obichukwu C. Nwobi….

imię i nazwisko

12 maja 2023 r

(miejscowość i data)

University of Nigeria, Nsukka, NIGERIA….

afiliacja

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021). Assessing Nigerian Butchers' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. Foods, 10(6), 1165*….. mój udział polegał na brała udział w organizacji badania, procesie wywiadu oraz walidacji/wizualizacji danych.

16/5/2023

……………………………………

data i podpis

dr hab Małgorzata Korzeniowska, prof. uczelni

03 kwietnia 2023 r

imię i nazwisko

(miejscowość i data)

UPWr

OŚWIADCZENIE

Oświadczam, że w pracy *Okpala, C. O. R., Nwobi, O. C., & Korzeniowska, M. (2021). Assessing Nigerian Butchers 'Knowledge and Perception of Good Hygiene and Storage .Practices: A Cattle Slaughterhouse Case Analysis. Foods, 10(6), 1165,* mój wkład polegał na wsółopracowaniu koncepcji, administrowaniu projektem, superwizji oraz walidacji/wizualizacji danych.

....

data i podpis

processes

MDPI

Article

Good Practices Contributing to Cleaner Food Production? A Preliminary Survey Analysis Involving Wrocław-Poland Food Retail Sector

Charles Odilichukwu R. Okpala [1,2]

[1] Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wrocław University of Environmental and Life Sciences, 50-630 Wrocław, Poland; charlesokpala@gmail.com

[2] UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia, Athens, GA 30602, USA

Abstract: Good practices are among the direct/indirect components that influence agrofood safety knowledge, and occupying quality assurance control facets within the (agrofood) product industry. Cleaner production involves an integrated preventive environmental strategy applied to processes, products, and services, which increases overall efficiency, and reduces risks to humans/environment. However, 'cleaner food production' appears neither yet clearly defined nor well established. In this preliminary survey analysis, how good practices would contribute towards achieving cleaner food production in the context of food retail sector was performed. Specifically, Wrocław-Poland served as a case reference targeting managers/supervisors given their expected service, experience, and expertise. The sampling technique used was the judgment/purposive type, and the research instrument took the form of a questionnaire. Managers'/supervisors' responses revealed significant differences ($p < 0.05$) across variables, with 'yes' emerging greater in most cases. Knowledge, experience, and expertise of good practices enabled the managers/supervisors connect with (some) cleaner production components. A total of 53 statistically significant correlations were found, wherein some showed perfect linear relationships. Specific to the context of (food) retail sector, the term "cleaner food production" could be defined as "*the effective and efficient utilization of good practices to deliver high-quality food retail products through environmental-friendly as well as sustainable processes*".

Keywords: good practices; productivity; agrofood industry; product improvement; sustainability

Citation: Okpala, C.O.R. Good Practices Contributing to Cleaner Food Production? A Preliminary Survey Analysis Involving Wrocław-Poland Food Retail Sector. *Processes* **2023**, *11*, 1224. https://doi.org/10.3390/pr11041224

Academic Editor: Chi-Fai Chau

Received: 27 February 2023
Revised: 3 April 2023
Accepted: 13 April 2023
Published: 15 April 2023

1. Introduction

The agrofood product supply chain remains very complex, with produce channels that are either direct or outside given localities [1–3]. Given the ever-increasing global population competing for the available agrofood resources, there continues to be increased efforts to sustain (agrofood) systems for the future [4]. A diagrammatic representation of a typical agrofood product supply chain is shown in Figure 1, which reveals how goods and services move from consumers to suppliers. The actual stage of product development depends on (product) type, from simple (for instance, a locally produced meat product) to complex (for instance, ingredients of a final meat product that can be obtained from different parts of the globe) [3]. Whereas the downstream flow involves the development of agrofood products within, the upstream flow involves the information from the end of the supply chain. More so, contracts that emanate from customers would allow the assembly of required inputs from different parts of the upstream chain [3]. In Europe, for instance, countries including France, Germany, Poland, and the UK possess very promising records of high-quality food retail outlets [5]. In Poland specifically, over the past decades, a number of challenges have been encountered by (Polish) enterprises, especially in adapting and adhering to the EU requirements involving agrofood production, from crop to livestock standpoints [6,7]. Despite the fluctuations that persist in the global supply chain, for a given manufactured food product to be realized at the market shelf would require in many cases a wide range of operations [8].

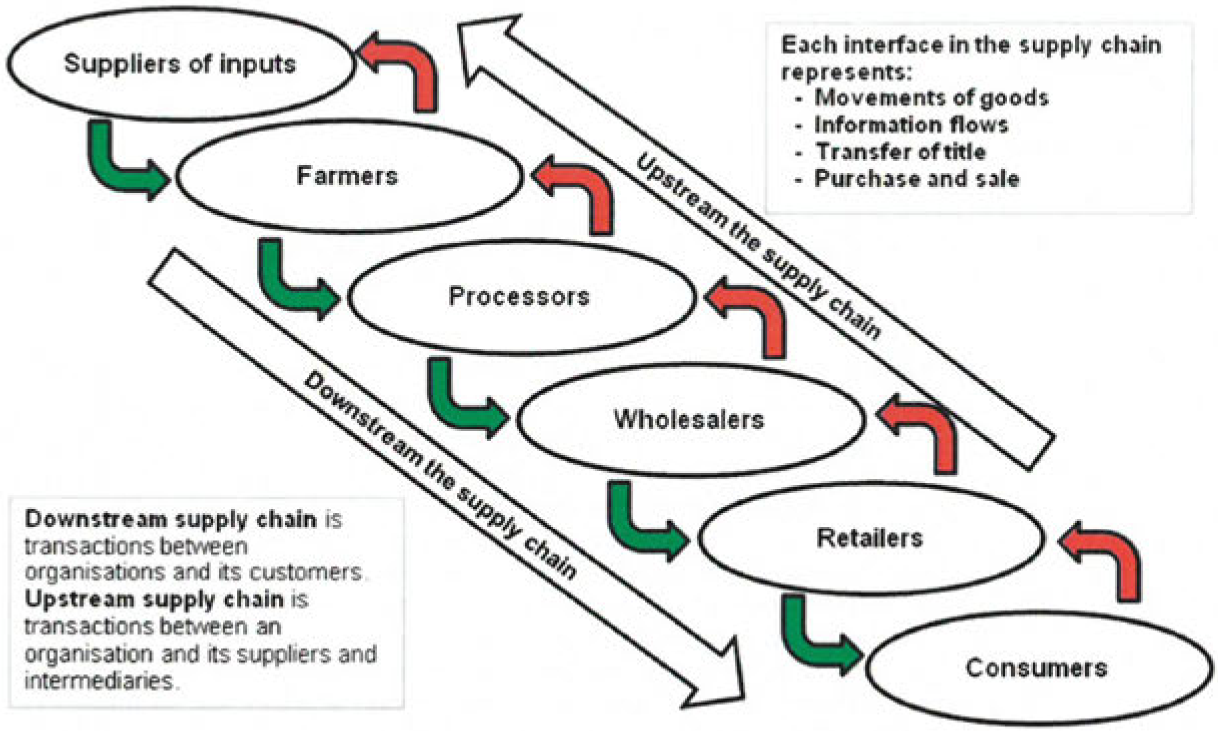

Figure 1. A diagrammatic representation of a typical agrofood product supply chain. From the consumers to the suppliers, the downstream (green) and upstream (red) direction flow of transactions takes place within the supply chain (Source: Costa-Font & Revoredo-Giha, [4]; Open access platform of London School of Economics Business Review).

Good practices, among the direct/indirect components that influence product safety knowledge within the agrofood industry, as shown in Figure 2, provide a strong foundation for handling both materials and their associated processes [3,9]. Despite occupying various quality assurance control facets within the food production pathway, good practices are of various types, namely: good agricultural practice (GAP), good catering practice (GCP), good hygiene practice (GHP), good manufacturing practice (GMP), good retail practice (GRP), good storage practice (GSP), and good transport practice (GTP) [3,10–12]. If good practices were to be viewed from a typical food operation unit to the broader spectrum of the food industry, three categories would emerge, namely: (a) those directly connected with food technology, e.g., GMP; (b) those directly connected with either food challenges, issues and or problems, e.g., GRP, GTP; and (c) those that deal with all activities concerning food handling, e.g., GHP [10,13]. Understanding the various good practices and their functions is necessary if the integrity of food safety and consumer protection within the agrofood product industry is to be consolidated [3,11]. Notably, the importance of food safety was tested during the global COVID-19 pandemic [14], wherein various aspects of the agrofood product industry, especially the retail sector, had to step up the quality delivery of their good practices. Notwithstanding this, an increased incidence occurrence, as well as an increased severity of foodborne pathogens, would still occur because of various negative operational activities, such as unsafe food sourcing, inadequacies in (food) processing, and cross-contamination [3,15]. That is why the agrofood product industry continually persists in discovering innovative strategies that improve consumer protection/food preservation [16].

Figure 2. Key direct/indirect components that influence food safety knowledge (Source: Okpala and Korzeniowska [3]; Permission to use given by Taylor and Francis Ltd.).

United Nations Environment Programme (UNEP) defines "cleaner production" as "the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment" [17]. In addition, the broad scope of cleaner production involves such areas as energy efficiency, environmental nexus, green sustainable chemistry, building construction, improved material handling, and toxic substances reduction, as well as waste elimination/management [18]. Sustainability change drivers that build cleaner production, according to Deprá et al. [19], strongly associate with the food production chain, which includes: (a) biophysical and environmental aspects; (b) innovation and technology aspects; (c) economic and market aspects; (d) institutional and political aspects; and (e) demographic and socio-cultural aspects. However, the concept of 'cleaner food production' in the scientific literature still appears to be not yet fully defined. Before this specific contribution, the author herein could only find three publications that specifically used 'cleaner food production' in their titles, which included the works of Xu et al. [20], Hou et al. [21], and Ding et al. [22]. Firstly, Xu et al. [20] presented cleaner food production as an approach in their investigation of three rice production modes in Panjin city, surrounding the Liaohe River in Northeast China. Secondly, Hou et al. [21] posited that rice-crayfish systems would not be a panacea for sustaining cleaner food production, which these workers deduced via economic and emergy analysis, together with nutrient use efficiency analyses of three rice production modes. Thirdly, Ding et al. [22] attempted to sustain cleaner food production via an optimized ratoon rice system in Jianghan Plain-China, regarding which these workers explained using a comprehensive emergy assessment. Contextualizing the three above-mentioned published works, could 'cleaner food production' either directly or indirectly address at least some key fundamental (food and its related) quality safety challenges and concerns within the agrofood product industry, and at the same time, promote environmentally friendly as well as sustainable processes? Well-constructed formulated questions could help develop interesting and influential theories [23,24]. Therefore, could formulating appropriate questions, and posing them to key stakeholders within the agrofood industry serve as a way to actualize such meeting points? Therefore, to supplement existing information, this preliminary survey analysis sought to delineate how good practices could contribute to achieving cleaner food production in the context of the food retail sector. Specifically, the food retail shops/stores in Wrocław-Poland served as a case reference for targeting managers/supervisors given their expected service, experience, and expertise.

2. A Short Background Literature Review

In this section, the author herein has performed a short background literature review, which aimed to provide some foundation about how cleaner production connects with the agrofood industry. It also provides a foundation about how good practices occupy a space within the food retail sector. To achieve this, the following subsections are succinctly presented, namely: (a) cleaner production's relevance to agrofood product industry; (b) good practices germane to food retail sector; and (c) consumer engagement, product stewardship, and waste management.

2.1. Cleaner Production's Relevance to Agrofood Product Industry

Increasingly, in its broader concept, cleaner production continues to gain a reputation within the agrofood product industry [20,25–28], the latter being among the world's largest sectors, occupying both domestic and industrial aspects of various countries. For instance, regarding food processing—part of the agrofood product industry contributes to organic pollution if designed with insufficient attention to the environment, which reiterates the importance of cleaner production [27]. A summary of some cleaner production implementations involving diverse sectors of the agrofood product industry specific to research focus, region of study, and (research) strategy, is shown in Table 1. Moreover, cleaner production research focus and strategy would vary across the agrofood product industry. For instance, cleaner production audit/methodology [29–31] and emergy analysis [20], together with case and survey studies [25,26,28], were shown in Table 1 among the research strategies. In addition, the majority of the above-mentioned cleaner production studies demonstrated, from recommendation options, an effective use of (cleaner production) checklist(s), foundations required for developing incentive schemes, and policy reforms and strategies, spreading across various regions of the globe.

Table 1. Summary of some cleaner production implementation involving diverse sectors of the agrofood product industry specific to research focus, and region of study, as well as (research) strategy.

References	Year of Study	Research Focus	Region of Study	Research Strategy
Ramjeawon [27]	2000	The extent to which environmental improvements are possible through cleaner production in the cane-sugar industry.	Mauritius (East Africa region)	Case-study approach, which evaluated the use of process water, waste streams, as well as options for water conservation in cane sugar factories.
Gurbuz, Kiran-Ciliz and Yenigun [29]	2004	Explored the applicability of cleaner production (CP) methodology for fifteen crude olive oil extraction involving small and medium-sized enterprises (SMEs), one olive oil refining plant and one pomace oil extraction plant	Turkey (representing Mediterranean region)	CP methodology employed a number of phases, from planning, organization, pre-assessment, assessment and feasibility aspects
Özbay and Demirer [30]	2007	Possible cleaner production (CP) opportunities for a milk processing facility via investigations of the general production process and resultant environmental loads	Turkey (representing the Mediterranean region)	Methodology for CP opportunities assessment involved two major steps:(1) Checklist preparation to assist auditing and CP opportunity assessment, to determine waste reduction options; (2) Implementation of mass balance analysis, which involves measurements/experimental analysis of mass flows, to determine inputs and outputs

Table 1. *Cont.*

References	Year of Study	Research Focus	Region of Study	Research Strategy
Massoud et al. [26]	2010	Assessing the factors influencing ISO14001 Environmental Management System implementation using the food industry as a case example	Lebanon (representing Middle East/Mediterranean region)	Primary data were collected using a field survey questionnaire administered to a representative sample of facilities
Rahim and Raman [31]	2015	Evaluating the feasibility of using cleaner production (CP) strategy in a fruit juice production plant	Malaysia (representing Asia region)	CP audit quantified the total resource consumption and waste generation, as well as areas of improvement (resource consumption and productivity)
Garrone et al. [25]	2016	Explaining how food manufacturers could prevent the degradation of generated surplus food into waste	Italy (representing Europe)	Through extensive literature and exploratory case studies, research questions were formulated. To corroborate the conceptual framework, descriptive case studies of Italian food manufacturers were conducted
Teller et al. [28]	2018	Identifying the root cause of food waste occurrence at the retail store level across different store formats and product categories	Europe (specific countries not mentioned)	Case studies that employed semi-structured interview with store managers of dominant retail store formats (i.e., super- and hypermarkets and discount and convenience stores)
Xu et al. [20]	2019	Evaluating the environment and economic performance of rice production modes in Panjin city surrounding Liaoha River Basin in Northeast China, using three production modes, namely: rice monoculture, conventional rice-crab, and optimized rice-crab	China (representing Asia)	(1) Emergy analysis was used to evaluate the sustainability of rice-crab coculture; and (2) Environmental and economic effects of three rice production modes were compared
Hou et al. [21]	2021	(a) to compare the nutrient use efficiencies of the three rice production modes through input–output analysis; b) to compare the economic performance of the three modes"; and c) to use emergy analysis to assess the environmental pressure of the three modes.	China (representing Asia)	Evaluation of study site and rice production systems; Economic analysis, specifically cost-benefit analysis, nutrient use efficiency, as well as energy analysis, all of which helped to estimate the emergent product's economic status.

In addition to Teller et al. [28], as shown in Table 1 determining the root cause of (food) waste occurrence in a food retail store, 'cleaner food production' appeared in the title of work conducted by Xu et al. [20] that considered the environmental and economic performance of three rice production modes in Panjin city, surrounding Liaohe River in Northeast China. Indeed, cleaner production has complex interactions with economic and social performance [32]. Despite these, its relevance to the agrofood industry, on one hand, should not be limited to waste elimination, water management, energy efficiency, and so on [33,34], but ought to extend to useful quality safety activities of food production processes. On the other hand, there could be environmental risks associated with the entire agrofood system, and associated with some inefficiencies (e.g., food loss, food waste, contaminations, etc.) [35–37]. With respect to the agrofood industry, however, Okpala, Korzeniowska, and Guiné [38] opined that in addition to the food product development pathway entailing major steps, there should be areas where good practices in food product development could help motivate consumers. Moreover, Fresner [39] understood that cleaner production, especially as a management strategy, may well initiate continuous improvement/prevention approaches with the end goal of saving the environment.

2.2. Good Practices Germane to Food Retail Sector

The agrofood product industry has to ensure affordable hazard measures for food (product) safety and (food) safety instruments, which facilitate the progress of local food management strategies [3,40]. Given the Codex Alimentarius Commission's code of practice for fruits and vegetables (CAC/RCP 53-2003), GAP has codes, standards, and regulations that have helped to curtail farm-level hazards before, during, and or after production [3]. Methodically, GAP identifies risks associated with individual fruits and vegetables based on available scientific data [41]. Within food safety and quality assurance, GCP identifies practical catering essentials/procedures in food processing, ensuring that they are displayed together with prepared items for consumption, remaining wholesome and safe [11,42]. GHP guidelines specify the monitoring of hygiene responsibilities within the food supply chain [43]. Both above-mentioned instances of GCP and GHP are applicable to the meat industry, and such guidelines would specifically constitute practical processes that return the work environment to its original condition and standard [10]. Under the EU hygiene regulation directive, for instance, the GHP makes the consumer directly responsible for food safety, despite the flexibility associated with the agrofood industry stakeholders in meeting their statutory obligations [44].

Applicable to the food retail sector, the agrofood products that require refrigeration would require GMP that involves (food product) development, processing, and marketing phases [45]. On one hand, the quality of GMP is the standard for operating procedures (SOPs) that serves as a guiding principle for agrofood product development [3]. To reduce food hazards and risks, on the other hand, GHP provides adequate specifics about food handling, preparation, and storage procedures [3]. More so, especially within the food retail sector, GRP would incorporate procedures and processes that ensure the delivery of requested (food) product(s) to the correct address within the satisfactory time period and under the required conditions [10]. Specific to the food retail industry, GRP would sustain the required (food) safety level through the following categories: (a) certification/training of managers; (b) cleaning and sanitation practices; (c) food storage conditions; and (d) temperature/time controls [15]. Overall, good practices would interconnect within the various aspects of the food processing industry. For example, GCP sometimes finds itself embedded in GHP [46], whereas GHP and GMP could also be part of GRP.

2.3. Consumer Engagement, Product Stewardship, and Waste Management

Consumer engagement, relevant in achieving cleaner production, is among the useful areas within the food retail sector which link to (consumer) behavior. To encourage behavioral change, Azapagic et al. [47] considered consumer engagement activities as very purposeful. Indeed, before either addressing or initiating any pressing environmental problem, consumer/individual well-being together with societal development is prioritized. To envision consumption as social activity/perceived need, there is a need for the active engagement of consumers so as to better their quality of life [48]. Importantly, across various sectors, consumer engagement platforms would associate with efficiency improvements that bring about (desirable) program successes [49]. Moreover, product stewardship within the agrofood industry would be demonstrated by responsible management, especially in situations where implementing a product lifecycle ranging from discovery, through manufacturing, to disposal stages, requires regulatory frameworks [50,51]. Further, product stewardship would assume the form of shared responsibility between organizations [52], for instance, within a given packaging supply chain. Indeed, product stewardship strategies, as reflected by stakeholders' perspectives, can integrate external environmental pressures into the product design and developmental processes [50]. Crucially, the success of cleaner production is unrealistic without human involvement and support. Empowering employees together with creating performance evaluation and reward systems should enhance the effectiveness of cleaner production [53]. Preferably at the time of waste disposal, as well as during the product design, (waste) production, and transport, etc., the policies associated with (product) stewardship would encourage built-in incentives/mechanisms that minimize the environmental impact [54].

In addition, when identifying dominant topics appearing in the *"Journal of Cleaner Production"*, Schober et al. [55] showed food production together with food-service-waste as being among the ten most characteristic topics. The concept of "food" would clearly appear with great importance in both food production and food service waste. Broadly, waste management, despite its complexities, is considered part of the generation, collection, and disposal system. In addition, implementing an effective waste disposal system requires an integrated approach, especially in the context of a sustainable society [56]. Global consumption and population within the past decade have increased with solid wastes, largely generated by the food industry [57]. More so, grocery retail sectors would produce substantial amounts of food waste, very critical to supermarkets given the negative socio-economic and environmental implications. In addition to the characterization and quantification of food waste streams, managerial attitudes and approaches to food waste mitigation are critical [58]. Elsewhere, other workers consider cleaner production as a voluntary approach to reduce waste [59].

3. Survey Methodology

3.1. Schematic Overview of Current Survey

The schematic overview of the current survey, from the identification of the study area/target population and the design of the research instrument, through to the questionnaire administration, data analysis, and discussion of the results using the relevant published information, is shown in Figure 3. This current survey seeks to delineate the degree to which good practices would contribute to cleaner food production specific to the context of the food retail sector. Further, the increasingly thriving food retail shops/stores in Wrocław-Poland [60] served as a case reference, specifically targeting their managers/supervisors given their expected service, experience, and expertise.

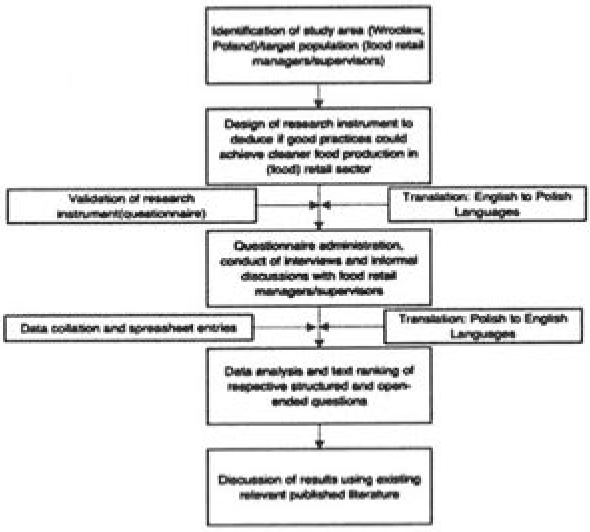

Figure 3. The schematic overview of the current preliminary survey, from the identification of the study area/target population and design of the research instrument, through to the questionnaire administration, data analysis, and discussion of results using relevant published information.

3.2. Ethical Considerations

As this current survey was strictly questionnaire-based, institutional ethics approval was not required. However, informed consent was orally obtained, confirmed by a request for permission to participate as stated on the first page of the questionnaire made available to all participants of this study. Consistent with the code of ethics of the World Medical Association Declaration of Helsinki, participants of this study were voluntary [61].

3.3. Survey Area, Sampling Technique, and Target Population

The area of focus in this current survey was the Wroclaw metropolis, situated in Lower Silesian Voivodeship, Poland. More so, the Wroclaw metropolis occupies the coordinates of latitude 51°06′00″ N, and longitude 17°01′59″ E, with a population of over 600,000 inhabitants [62,63]. The sampling technique used for this preliminary survey was the judgement/purposive type; the managers/supervisors of food retail shops/stores were targeted given their expected service and experience, as well as expertise. More so, the food retail shops (and their respective managers/supervisors) were holistically representative of others found at other places elsewhere in Poland in terms of their size, volume of responsibilities, and workforce.

3.4. Development of Research Instrument

The research instrument took the form of a questionnaire, which incorporated the author's combined specialist experience, expertise, and knowledge, additionally supplemented with the synthesized relevant literature [64]. To ensure the questions presented in the research instrument (that is, the questionnaire) were authentic and reliable, content validation, as highly recommended by Taherdoost [65], was employed. Specifically, the content validation process was implemented by a food retail sector expert with many years of work experience. The content validation process involved a critical evaluation of the research instrument, which allowed for useful amendments to be made, as deemed most appropriate. This process helped to enhance the relevance of the survey questions, which constructively aligned with the research objective and context [65]. Two native Polish speakers with a strong command of the English language were recruited to expertly perform not only the translation and re-translation of the research instrument from English to Polish, and thereafter from Polish to English, but also the conduction of the interviews and recording of the responses. Throughout the translation process, the content and context of the questions, as well as their corresponding responses, were adequately maintained.

3.5. Survey Questions, Food Retail Workday, and Interview Activity

In the questionnaire shown to the managers/supervisors, Figure 4 was presented on the front page, followed by survey questions on the subsequent page. Specifically, there were a total of 11 questions, which included: (a) Do you believe good practices are essential to your food retail shop? (b) Do you believe good practices provide a foundation for agro-food product quality? (c)Are there any cleaner production components (Refer to Figure 4) you identify with?' (d) Do you apply any of the cleaner production components(Refer to Figure 4) in your food retail shop? (e) Do you engage with customers that come into your food retail shop? (f) Do you think the presence of customers helps improve your overall work efficiency in the food retail shop/store? (g) Are you responsible for customers as well as product safety in your food retail shop? (h) Do you share responsibilities in your food retail shop? (i) Are there any waste disposal challenges that you encounter at your food retail shop/store? (j) Are both the manager and management involved in the waste elimination process at this food retail shop/store? (k) Based on the above-mentioned questions, would you consider the utilization of cleaner production in the food retail shop/store to be useful?

When Figure 4 was shown to the managers/supervisors, this question was verbally presented to them: "Could it be possible for cleaner production components and types of good practices in the food industry to either combine or at least meet to form "cleaner food production?" As the managers/supervisors reflected on the figure and the question verbally posed to them, they perused the survey questions, of which there were 11 in total. The survey questions required either 'yes', 'no', or 'not sure' responses. An open-ended option was provided to allow for some informal discussions with the managers/supervisors. From the author's previous survey experience [64], the number of survey questions in this current work was considered appropriate and sufficient so as not to deter the food retailer managers'/supervisors' participation.

A total of eighty-five (N = 85) food retail managers/supervisors at their respective shops/stores were interviewed during the survey period, and none participated more than once. Chiefly, a typical workday of a food retail store manager/supervisor(alongside their respective co-workers) starts with a security inspection to ensure that the shop whilst closed remained intact. There is also general housekeeping, which involves a quick brushing/mopping of the floor, checking for any kind of spillages and situations that could pose safety hazards at the workplace, and an operational perusal of the shop's/store's electronic and electrical appliances. There is also the point of sale (POS) check, which may follow the evaluation of stock, either to place or replace new items, check expiry dates, appropriate price tags of food products on the shelves, etc.

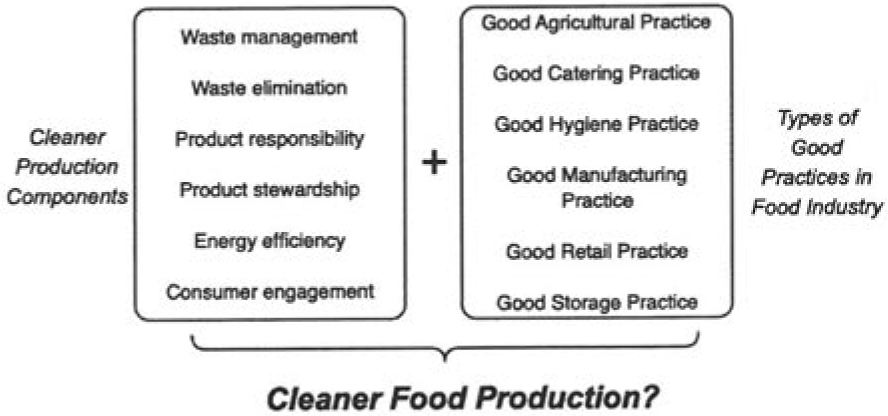

Figure 4. Could it be possible for cleaner production components and types of good practices in the food industry to either combine or at least meet to form "cleaner food production"?

The interview process involved several visits to various food retail shops/stores around Wrocław-Poland, which cumulated the data collection period that lasted a total of 12 weeks. The idea was to interview one manager/supervisor per food retail shop. The criteria for selecting a retail shop/store were that it must have both fresh and packaged food items, which included any form of meat products. During the interview process, the food retail store managers/supervisors, in most of their responses to the questions, engaged effectively via informal discussions when they were either at work or had already accomplished their expected daily tasks. Neither the names, gender, or personal information of the managers/supervisors, nor those of their respective shops, were asked for. This helped to enhance their participation together with the provision of non-biased information as much as possible. The interview times at the food retail stores were varied because they were dependent on the managers'/supervisors' availability and convenience. There were instances where the food retail managers/supervisors were very occupied and could not attend to all of the questions and requested the interviewers to return on another day. In addition, there were other instances where the managers/supervisors showed some reluctance to provide responses to some questions despite their willingness to participate. When such instances transpired, the interviewers did not pressure the managers/supervisors but gratefully accepted their efforts given their willingness to participate despite their very occupied schedules.

3.6. Statistical Analysis

The emergent data, having fulfilled the assumptions of non-parametric distribution, were subject to the Kruskal-Wallis(K-W) analysis of variance(ANOVA) test, which established the statistical significance between the response variables. The results of the analyzed data were presented via frequencies, percentages, *p*-values, and K-W statistics. When the correlation was needed, Spearman's test was implemented and reported via correlation coefficient (r) and probability (*p*) values. The probability level for statistical significance was set at $p < 0.05$ (95% confidence). GraphPad Prism version 9.4.1 (458) for macOS (GraphPad Software LLC, San Diego, CA, USA) was used to run the statistical analysis. The open-ended responses were categorized using a word-based technique, previously described by Okpala, Nwobi, and Korzeniowska [64], with slight modifications. This involved the sorting of the actual text responses provided by the food retail managers/supervisors to identify a specific theme, thereafter being tallied to ascertain the frequency of these occurrences, which were subsequently reported in percentages.

4. Results and Discussion

4.1. Managers'/Supervisors' Responses to Question

Deducing the knowledge base of food retail supervisors/managers specifically related to their good practices, and how this is utilized to achieve cleaner food production, would require the use of appropriate open-ended questions. Table 2 presents the managers'/supervisors' responses concerning the extent to which their good practices would contribute to achieving cleaner food production in their respective (food) retail sectors/shops. Significant differences were found across response variables ($p < 0.05$), with 'Yes' being greater in most cases. However, the response of 'no' seemed greater only regarding waste disposal challenges in the food retail shop. Cleaner production components that the respondents identified more with, as well as engaging with customers that come to the food retail shop/store, both obtained the highest K-W statistic (70.37), whereas the manager and management involvement in the waste elimination process, obtained the least (40.82). This may well suggest the managers/supervisors in this current study considered cleaner production components that they identified more with to be equally as important as engaging with customers that come to their food retail shops/stores. Importantly, the K-W statistic remains among the most robust and valid means of ranking variance differences [66]. Whether differences between given groups occur by chance or are genuine, the K-W statistic would capably provide a way out by comparing the sample with population curves, which forms the basis of the H-test that aims to ascertain the same form of distribution between samples and the population [67].

With respect to the (food) retail sector, and applicable to other aspects of the food service industry, the integrity of food safety would be compromised if the job roles of those who assure quality were neither clearly defined nor well understood [3,11]. Further, imagine a situation wherein a given meat industry's retail manager/supervisor underperforming at food safety designated tasks, the outcome could subject such enterprise to become increasingly vulnerable to the emergence of foodborne risks. Thus, there is a need for increased emphasis on good practices within the domain of consumer protection and food quality [3,11]. In the current survey, some respondents who indicated 'yes' for good practices being essential to the food retail shop (N = 52; 61.2%) did so because they considered it a mandatory activity to avoid being fired (N = 5; 9.6%); a duty/responsibility (N = 3; 5.8%); a way to keep everything (in the shop) clean and good looking for customers (N = 2; 3.9%); a method of providing (good practices) knowledge as an opportunity to educate other people (N = 1; 1.9%); a contribution to saving the environment/planet (N = 1; 1.9%); and a way to help the shop to grow (N = 1; 1.9%). Some respondents who indicated 'yes' regarding whether good practices provided a foundation for the agrofood product quality (N = 47; 55.3%) did so because it was deemed compulsory (N = 2; 4.3%); it was considered useful in ensuring a clean shop (N = 1; 2.1%), and it helped to create environmental awareness (N = 1; 2.1%). Indeed, good practices would cut across all key aspects of the (food) supply chain processes within the agrofood industry [3,9]. More so, both consumer engagement—being purposeful for achieving workplace improvement and product stewardship—that itself empowers employees, can collectively increase the effectiveness of cleaner production [47,49,52,53]

Table 2. Managers'/ supervisors' responses to questions about the extent at which their good practices would contribute to achieving cleaner food production in their respective (food) retail sectors/shops.

No.	Questions Posed to the Food Retail Managers/Supervisors	Response Variables	Frequency of Response	*p*-Value	Kruskal-Wallis Statistic
1	Do you believe good practices are essential to your food retail shop?	Yes	61.2% (N = 52)	<0.0001	62.28
		No	2.4% (N = 2)		
		Not sure	8.2% (N = 7)		
2	Do you believe good practices provide a foundation for agrofood product quality?	Yes	55.3% (N = 47)	<0.0001	57.20
		No	2.4% (N = 2)		
		Not sure	12.9% (N = 11)		
3	Are there any cleaner production components (as shown in Figure 4) you identify with?'	Yes	70.6% (N = 60)	<0.0001	70.37
		No	4.7% (N = 4)		
		Not sure	0.0% (N = 0)		
4	Do you apply any of the cleaner production components (as shown in Figure 4) in your food retail shop?	Yes	69.4% (N = 59)	<0.0001	69.36
		No	7.1% (N = 6)		
		Not sure	4.7% (N = 4)		
5	Do you engage with customers that come into your food retail shop?	Yes	77.7% (N = 66)	<0.0001	70.37
		No	16.5% (N = 14)		
		Not sure	0.0% (N = 0)		
6	Do you think the presence of customers helps improve your overall work efficiency in the food retail shop/store?	Yes	60.0% (N = 51)	<0.0001	61.26
		No	20.0% (N = 17)		
		Not sure	14.1% (N = 12)		
7	Are you responsible for the customers as well as product safety in your food retail shop?	Yes	45.9% (N = 39)	<0.0001	49.05
		No	32.9% (N = 28)		
		Not sure	0.0% (N = 0)		
8	Do you share responsibilities in your food retail shop/store?	Yes	43.5% (N = 37)	<0.0001	47.00
		No	35.3% (N = 30)		
		Not sure	2.4% (N = 2)		
9	Are there any waste disposal challenges that you encounter at your food retail shop/store?	Yes	16.5% (N = 14)	<0.0001	47.00
		No	43.5% (N = 37)		
		Not sure	15.3% (N = 13)		
10	Are both manager and management involved in the waste elimination process at this food retail shop/store?	Yes	36.5% (N = 31)	<0.0001	40.82
		No	31.8% (N = 27)		
		Not sure	8.2% (N = 7)		
11	Based on the above-mentioned questions, would you consider the utilization of cleaner production in the food retail shop/store to be useful?	Yes	43.5% (N = 37)	<0.0001	47.00
		No	7.1% (N = 6)		
		Not sure	23.5% (N = 20)		

In this current survey, when the respondents were shown the cleaner production components (refer to Figure 4), some were able to identify with all of them (N= 60; 70.6%), which might suggest their managerial efficiency, proactivity, and productivity. From these, some respondents further indicated having applied all of the shown cleaner production components (N = 14; 60.9%), whereas for some others just a few were implemented (N = 9; 39.1%). The shown cleaner production components that some respondents were specifically able to identify with included waste management (N = 5; 8.3%), waste elimination (N = 3; 13.04%), energy efficiency (N = 2; 8.7%), and customer engagement (N = 1; 4.4%). This finding further connects the complex interactions associated with why its relevance to the agrofood industry should not be limited to energy efficiency, waste elimination, etc. [32–34]. Probably, the respondents demonstrating a reasonably good practice capacity could identify with some cleaner production components. This is where the concept of product stewardship plays a very important role, especially the involvement of responsible management that aims to implement waste disposal [50,51]. This is also why the food service industry has a significant role to play, especially in addressing the concerns of food waste [55]. In the current survey, a reasonable number of respondents engaged with customers in their food retail shops/stores (N= 66; 77.7%), some of whom attributed this to be among their corporate responsibilities (N = 12; 18.18%) and a component of their personnel work culture (N = 5; 7.58%), which would cumulatively enhance their communication skills (N = 2; 3.0%) and strengthen their customer support system (N = 9; 13.6%). More so, a reasonable proportion of the respondents considered the presence of customers to be a likely contributor to improving the efficiency of food retail shops/stores (N = 51; 60.0%). Through their knowledge of good practices, the respondents' ability to apply some cleaner production components to their food retail shop/store probably helps to encourage customers to return (N = 5; 9.8%) and recommend the food retail shop to other customers (N = 6; 11.76%). Indeed, cleaner production evidently associates with economic, social, and environmental benefits to an organization's activities, as well as the culture, especially when the target is to implement a short-to-long-term vision [59].

Quality, whether in terms of concept, content, or context, has to move from people through to the food technological processes, prior to being received by the consumer in a product on the market shelf [3,68,69]. In this current survey, a promising number of respondents demonstrated some responsibility regarding consumer and product safety specific to their food retail shop (N= 39; 45.9%), some of whom further engaged in such activities as cleaning the entire shop and its surroundings (N = 8; 20.5%) alongside checking the quality of food products (N = 8; 20.5%). Additionally, nearly half of the respondents indicated they shared some of their responsibilities (N = 37; 43.5%), wherein some believed it would expedite the daily work and ease the workload (N = 13; 35.1%). A reasonable number of respondents considered waste disposal not to be a challenge (N= 37; 43.5%), even though some others indicated otherwise (N = 14; 16.5%), from whom some specifically indicated the reason as being the inadequacy of disposal bins (N = 9; 64.3%). Further, a reasonable number of respondents indicated both managers' and management's involvement in the waste elimination process (N = 31; 36.5%). Moreover, Schober et al. [55] understood that 'food' is given very high importance in terms of food service waste, especially those that emanate from (food) retail shops/stores that need to be mitigated [58]. In addition, there were a number of respondents that considered cleaner production in food retail shops to be useful (N = 37; 43.5%), some of whom believed such knowledge would strengthen (food)product quality for the customers (N = 7; 18.9%), as well as demonstrate their corporate responsibility (N = 7; 18.9%). Notably, Stone [70] identified some key elements reflective of cleaner production uptake to actualize organizational change, culture, and key attitudes. With respect to organizational change, there were cleaner production options together with a recognition of the economic benefits. With respect to organizational culture, there were barriers from senior management to improving the environment, and the staff was encouraged to identify areas to improve the environment. With respect to key attitudes, reducing waste would require changing both products and processes.

4.2. Correlation Outcomes to "Yes" Responses

Given the nature of the managers'/supervisors' 'yes' responses about how their good practices would contribute to cleaner food production, it was deemed necessary to find out whether any relationship existed between the various responses, and therefore, a correlation analysis was performed. The correlation outcomes between the 'yes' responses to questions from managers/supervisors regard how their good practices would contribute to cleaner food production, as shown in Table 3. There was a total of 53 statistically significant correlations, all of which were positive, from which some showed perfect linear relationships. For instance, in the food retail shop, although the good practices are an essential factor statistically correlated ($p < 0.05$) with the foundation of agrofood product quality ($r = 0.787$); the cleaner production components' application ($r = 0.664$)/identification ($r = 0.609$); the presence of customers to improve (food retail) shop's/store's overall efficiency ($r = 0.917$); the responsibility of customers' product safety ($r = 0.604$); the shared responsibility ($r = 0.586$); the challenges encountered during waste disposal ($r = 0.249$); and the usefulness of utilizing cleaner production (in the food retail shop/store) ($r = 0.586$), yet good practices being a foundation itself would strongly correlate with all of the above-mentioned elements. As the various good practices would adhere to standards/regulations [41–43], with the stakeholders within the agrofood industry having their responsibilities shared, the activities of customer engagement should help address not only the emerging socio-environmental concerns but also the incorporation of efficiency improvements and program successes [47–49].

Another instance, and not surprising, is the fact that identification of cleaner production components were statistically correlated ($p < 0.05$) with its application ($r = 0.918$); the presence of customers to improve food retail shop's/store's overall work efficiency ($r = 0.559$); the managers/supervisors' responsibility to customers/product safety ($r = 0.368$); and the shared responsibility (for the food retail shop/store) ($r = 0.357$); as well as the manager/management involvement in waste elimination process ($r = 0.298$). Largely, the application of cleaner production components would correlate positively with the others as well. Interestingly, engaging with customers in food retail shops/stores would demonstrate a perfect relationship ($r = 1.000$) with good practices being essential and the latter providing the foundation for agrofood quality and the identification of cleaner production components ($p < 0.001$). Interestingly also, engaging with customers in food retail shops/stores would demonstrate a perfect relationship ($r = 1.000$) with improving overall work efficiency, the responsibility of customer/product safety, the sharing of responsibilities, the waste disposal challenges encountered, the manager/management involvement in the waste elimination process, and the usefulness of utilizing cleaner production ($p < 0.001$). Clearly, the above-mentioned perfect association that involves engaging with customers in food retail shops/stores, specifically within the service delivery of managers/supervisors, further reiterates the interrelatedness of consumer engagement, product stewardship, and waste management. More so, the perfect correlation outcomes of the present work, as shown in Table 3, could cumulatively suggest why product stewardship contributes to shared responsibility, especially in the disposal as well as recycling of products at the end of the life cycle [50–52].

Table 3. Correlation outcomes between 'yes' responses to questions from managers/supervisors regards how their good practices would contribute to cleaner food production.

Variable	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A2	[1] 0.787									
	[2] <0.001 *									
A3	0.609	0.480								
	<0.001 *	<0.001 *								
A4	0.664	0.522	0.918							
	<0.001 *	<0.001 *	<0.001 *							
A5	1.000	1.000	1.000	1.000						
	<0.001 *	<0.001 *	<0.001 *	<0.001 *						
A6	0.917	0.858	0.559	0.609	1.000					
	<0.001 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *					
A7	0.604	0.768	0.368	0.401	1.000	0.659				
	<0.001 *	<0.001 *	0.002 *	0.001 *	<0.001 *	<0.001 *				
A8	0.586	0.745	0.357	0.389	1.000	0.639	0.970			
	<0.001 *	<0.001 *	0.003 *	0.001 *	<0.001 *	<0.001 *	<0.001 *			
A9	0.249	0.317	0.152	0.165	1.000	0.272	0.414	0.427		
	0.045 *	0.010 *	0.228	0.188	<0.001 *	0.028 *	0.001 *	<0.001 *		
A10	0.488	0.621	0.298	0.324	1.000	0.532	0.808	0.833	0.514	
	<0.001 *	<0.001 *	0.015 *	0.008 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *	
A11	0.586	0.745	0.357	0.389	1.000	0.639	0.970	1.000	0.427	0.833
	<0.001 *	<0.001 *	0.003 *	0.001 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *	<0.001 *

Key: [1] Correlation coefficient; [2] Probability level; * Correlation data considered to be significantly different at $p < 0.05$; A1 = Indicated 'yes' to "Do you believe good practices are essential to your food retail shop?"; A2 = Indicated 'yes' to "Do you believe good practices provide foundation for agrofood product quality?"; A3 = Indicated 'yes' to "Are there any cleaner production components (as shown in Figure 4) you identify with?"; A4 = Indicated 'yes' to "Do you apply any of the cleaner production components(as shown in Figure 4) in your food retail shop?"; A5 = Indicated 'yes' to "Do you engage with customers that come into your food retail shop?" A6 = Indicated 'yes' to "Do you think the presence of customers help improve your overall work efficiency in the food retail shop/store?"; A7 = Indicated 'yes' to "Are you responsible for customers as well as product safety in your food retail shop?"; A8 = Indicated 'yes' to "Do you share responsibilities in your food retail shop? "; A9 = Indicated 'yes' to "Are there any waste disposal challenges that you encounter at your food retail shop/store?"; A10 = Indicated 'yes' to "Are both manager and management involved in the waste elimination process at this food retail shop/store?"; as well as A11 = Indicated 'yes' to "Based on the above-mentioned questions, would you consider the utilization of cleaner production in the food retail shop/store to be useful?".

5. Conclusions

How good practices would contribute to achieving cleaner food production in the context of the food retail sector has been surveyed. For clarity, Wrocław-Poland served as a reference location, and the managers/supervisors were targeted given their expected service, experience, and expertise. Through their responses, the managers/supervisors demonstrated a capacity for understanding that good practices contribute towards achieving cleaner food production specific to the context of their food retail shops/stores. More so, the utilization of cleaner production in food retail would significantly associate with waste elimination. Despite the promising findings of this preliminary survey analysis, a limitation could be that not all of the survey questions were attempted by the participants. Nonetheless, there were a total of 53 statistically significant correlations, all of which were positive. The perfect correlation outcomes could cumulatively suggest why product stewardship contributes to shared responsibility, especially in the disposal as well as recycling of products at the end of life cycle.

Ultimately, 'cleaner food production' would suggest either directly or indirectly addressing at least some key fundamental (food and its related) quality safety challenges within the agrofood product industry, and at the same time, promoting environmentally friendly/sustainable processes. Therefore, considering the entirety of this current preliminary survey analysis, the 'cleaner food production' specific to the context of the (food) retail sector and service, could be defined as *"the effective and efficient utilization of good practices to deliver high quality food retail products through environmentally friendly, as well as sustainable, processes"*. More surveys that incorporate such elements as demography, education, experience, corporate responsibility, retailer classification, and types within the research space (independent shops, grocery, local chains, national chains, international chains, and market shares, etc.) are warranted, which should help to provide a wider context regarding the food retail sector, as well as strengthening the debate about 'cleaner food production'. Additionally, more studies that bring together various "cleaner production" and "food technological" components are warranted, which should provide insightful knowledge and help increase the understanding that underpins "cleaner food production".

Funding: This work was supported by Wrocław University of Environmental and Life Sciences (Poland) under the Ph.D. research program 'Doctoral student grant at the Doctoral School of Wrocław University of Environmental and Life Sciences' no: N020/0011/20. Publication financed by project UPWR 2.0: international and interdisciplinary programme of development of Wrocław University of Environmental and Life Sciences, co-financed by the European Social Fund under the Operational Program Knowledge Education Development, under contract no. POWR.03.05.00-00-Z062/18 of 4 June 2019.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Verbal consent was obtained from all managers/supervisors prior to their participation in this questionnaire-based study.

Data Availability Statement: Data is contained within the article. Additionally, due to project restrictions, the Polish translation of the survey questionnaire is not shared.

Acknowledgments: Author C.O.R.O. appreciates the funding support from Wrocław University of Environmental and Life Sciences, Poland.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Okpala, C.O.R. Towards Sustaining Global Food Systems for the Future. *Front. Sustain. Food Syst.* **2020**, *4*, 3. [CrossRef]
2. Dora, M.; Kumar, M.; Goubergen, D.V.; Molnar, A.; Gellynck, X. Food quality management system: Reviewing assessment strategies and feasibility study for European food small and medium-sized enterprises. *Food Control* **2013**, *31*, 607–616. [CrossRef]
3. Okpala, C.O.R.; Korzeniowska, M. Understanding the relevance of quality management in agro-food product industry: From ethical considerations to assuring food hygiene quality safety standards and its associated processes. *Food Rev. Int.* **2021**, *39*, 1–74. [CrossRef]
4. Costa-Font, M.; Revoredo-Giha, C. COVID-19: The Underlying Issues Affecting the UK's Food Supply Chains. LSE Business Review. Available online: https://blogs.lse.ac.uk/businessreview/2020/03/25/covid-19-the-underlying-issues-affecting-the-uks-food-supply-chains/ (accessed on 3 March 2023).
5. Retail index, Rankings and Profiles of Food Retailers in Europe, America, Asia and Africa. Available online: https://www.retail-index.com/Sectors/FoodRetailersinEuropeandworldwide.aspx?gclid=CjwKCAjwztL2BRATEiwAvnALctKAmLM5vMA7bIRkBn978FBAqgbwlRWjEZUI9flzdxqMZ3gddVYx1BoCUlUQAvD_BwE (accessed on 2 June 2020).
6. Buko, J.; Duda, J.; Makowski, A. Food Production Security in Times of a Long-Term Energy Shortage Crisis: The Example of Poland. *Energies* **2021**, *14*, 4725. [CrossRef]
7. Trafialek, J.; Kolozyn-Krajewska, D. Implementation of safety assurance system in food production in Poland. *Pol. J. Food Nutr. Sci.* **2011**, *61*, 115–124. [CrossRef]
8. Wrzesińska-Kowal, J.; Drabarczyk, K. Food production in Poland, compared to selected European Union Member states. *Probl. World Agric. Probl. Rol. Swiat.* **2014**, *14*, 205–214. [CrossRef]
9. Varzakas, T.; Tzia, C. *Handbook of Food Processing, Food Safety, Quality and Manufacturing Processes*; CRC Press: Boca Raton, FL, USA, 2016; p. 676. ISBN 978-1-4987-2178-3.
10. Raspor, P. Total food chain safety: How good practices can contribute? *Trends Food Sci. Technol.* **2008**, *19*, 405–412. [CrossRef]
11. Raspor, P.; Jevšnik, M. Good Nutritional Practice from Producer to Consumer. *Crit. Rev. Food Sci. Nutr.* **2008**, *48*, 276–292. [CrossRef]
12. Selmat, J.; Iqbal, S.Z. (Eds.) *Food Safety: Basic Concepts*; Recent Issues and Future Challenge Springer International Publishing: Cham, Switzerland, 2016; p. 164. ISBN 978-3-319-39253-0.

13. Nedovic, V.; Raspor, P.; Levic, J.; Saponjac, V.T.; Barbosa-Cánovas, G.V. *Emerging and Traditional Technologies for Safe, Healthy and Quality Food*; Springer International Publishing: Cham, Switzerland, 2016; p. 487. ISBN 978-3-319-24038-1.
14. Shahidi, F. Does COVID-19 affect food safety and security? *J. Food Bioact.* **2020**, *9*, 1–3. [CrossRef]
15. Gole, S. Unit 14: Good Retail Practices, Good Transport Practices and Nutrition Labeling. 2018. Available online: https://www.14.139.199/bitstream/123456789/42855/1/Unit-14.pdf/ (accessed on 14 March 2020).
16. Voysey, P.A.; Brown, M. Microbiological risk assessment: A new approach to food safety control. *Int. J. Food Microbiol.* **2000**, *58*, 173–179. [CrossRef]
17. Yüksel, H. An empirical evaluation of cleaner production practices in Turkey. *J. Clean. Prod.* **2008**, *16*, S50–S57. [CrossRef]
18. Journal of Cleaner Production. Available online: https://www.journals.elsevier.com/journal-of-cleaner-production (accessed on 2 June 2020).
19. Deprá, M.C.; Dias, R.R.; Zepka, L.Q.; Jacob-Lopes, E. Building cleaner production: How to anchor sustainability in the food production chain? *Environ. Adv.* **2022**, *9*, 100295. [CrossRef]
20. Xu, Q.; Wang, X.; Xiao, B.; Hu, K. Rice-crab coculture to sustain cleaner food production in Liaohe River Basin, China: An economic and environmental assessment. *J. Clean. Prod.* **2019**, *208*, 188–198. [CrossRef]
21. Hou, J.; Wang, X.; Xu, Q.; Cao, Y.; Zhang, D.; Zhu, J. Rice-crayfish systems are not a panacea for sustaining cleaner food production. *Environ. Sci. Pollut. Res.* **2021**, *28*, 22913–22926. [CrossRef]
22. Ding, Z.; Hu, R.; Styles, D.; Wang, X.; Tian, Y.; Cao, Y.; Hou, J. Optimized ratoon rice system to sustain cleaner food production in Jianghan Plain, China: A comprehensive emergy assessment. *Environ. Sci. Pollut. Res.* **2022**, *29*, 24639–24650. [CrossRef] [PubMed]
23. Sandberg, J.; Alvesson, M. Ways of constructing research questions: Gap-spotting or problematization? *Organization* **2011**, *18*, 23–44. [CrossRef]
24. Okpala, C.O.R. Reflecting in the Woods: Can it Help to Enhance the Formulation of (our) Research Questions? *BioResources* **2017**, *12*, 4490–4494. [CrossRef]
25. Garrone, P.; Melacini, M.; Perego, A.; Sert, S. Reducing food waste in food manufacturing companies. *J. Clean. Prod.* **2016**, *137*, 1076–1085. [CrossRef]
26. Massoud, M.A.; Fayad, R.; El-Fadel, M.; Kamleh, R. Drivers, barriers and incentives to implementing environmental management systems in the food industry: A case of Lebanon. *J. Clean. Prod.* **2010**, *18*, 200–209. [CrossRef]
27. Ramjeawon, T. Cleaner production in Mauritian cane-sugar factories. *J. Clean. Prod.* **2000**, *8*, 503–510. [CrossRef]
28. Teller, C.; Holweg, C.; Reiner, G.; Kotzab, H. Retail store operations and food waste. *J. Clean. Prod.* **2018**, *185*, 981–997. [CrossRef]
29. Gurbuz, S.; Kiran-Ciliz, N.; Yenigun, O. Cleaner production implementation through process modifications for selected SMEs in Turkish olive oil production. *J. Clean. Prod.* **2004**, *12*, 613–621. [CrossRef]
30. Özbay, A.; Demirer, G.N. Cleaner production opportunity assessment for a milk processing facility. *J. Environ. Manag.* **2007**, *84*, 484–493. [CrossRef] [PubMed]
31. Rahim, R.; Raman, A.A.A. Cleaner production implementation in a fruit juice production plant. *J. Clean. Prod.* **2015**, *101*, 215–221. [CrossRef]
32. Fan, Y.V.; Chin, H.H.; Klemeš, J.J.; Varbanov, P.S.; Liu, X. Optimisation and process design tools for cleaner production. *J. Clean. Prod.* **2020**, *247*, 119181. [CrossRef]
33. Lemaire, A.; Limburg, S. How can food loss and waste management achieve sustainable development goals. *J. Clean. Prod.* **2019**, *234*, 1221–1234. [CrossRef]
34. Zamri, G.B.; Azizal, N.K.A.; Nakamura, S.; Okada, K.; Nordin, N.H.; Othman, N.-A.; Akhir, F.N.M.; Sobian, A.; Kaida, N.; Hara, H. Delivery, impact and approach of household food waste reduction campaigns. *J. Clean. Prod.* **2020**, *246*, 118969. [CrossRef]
35. Amicarelli, V.; Fiore, M.; Bux, C. Hidden flows assessment in the agri-food sector: Evidence from the Italian beef system. *Br. Food J.* **2020**, *123*, 384–403. [CrossRef]
36. Clark, M.; Springmann, M.; Rayner, M.; Harrington, R.A. Estimating the environmental impacts of 57,000 food products. *Environ. Sci.* **2022**, *119*, e21205841190. [CrossRef]
37. Notarnicola, B.; Tassielli, G.; Renzulli, P.A.; Castellani, V.; Sala, S. Environmental impacts of food consumption in Europe. *J. Clean. Prod.* **2017**, *140*, 753–765. [CrossRef]
38. Okpala, C.O.R.; Korzeniowska, M.; Guiné, R.P.F. Good practices in food product development processes: Some keys to motivating the consumer. In Proceedings of the Presentation delivered at the International Web Conference on Food Choice & Eating Motivation, Online, 19–20 May 2022.
39. Fresner, J. Cleaner production as a means for effective environmental management. *J. Clean. Prod.* **1998**, *6*, 171–179. [CrossRef]
40. Aruoma, C.I. The impact of food regulation on the food supply chain. *Toxicology* **2006**, *221*, 119–127. [CrossRef]
41. da Cruz, A.G.; Cenci, S.A.; Maia, M.C.A. Good agricultural practices in a Brazilian produce plant. *Food Control* **2006**, *17*, 781–788. [CrossRef]
42. Raspor, P.; Ambrožič, M.; Jevšnik, M. Food Chain Safety Management Systems: The Impact of Good Practices. In *Advances in Food Process Engineering Research and Applications*; Yanniotis, S., Taoukis, P.S., Stoforos, N.G., Karathanos, V.T., Eds.; Food Engineering Series: New York, NY, USA, 2013; p. 19. [CrossRef]
43. Sikora, T.; Strada, A. Safety and quality assurance and management systems in food industry: An overview. In *The Food Industry in Europe*; Agricultural University of Athens: Ateny, Greece, 2005.

44. Lelieveld, H.L.M.; Mostert, M.A.; Holah, J.; White, B. *Hygiene in Food Processing*; Woodhead Publishing Ltd.: Cambridge, UK, 2003; p. 390. ISBN 1855734664.
45. Moberg, L. Good manufacturing practices for refrigerated foods. *J. Food Prot.* **1989**, *52*, 363–367. [CrossRef] [PubMed]
46. Wallace, C.A.; Sperber, W.H.; Mortimore, S.C. *Food Safety for the 21st Century: Managing HACCP and Food Safety throughout the Global Supply Chain*, 2nd ed.; John Wiley and Sons, Ltd.: Oxford, UK, 2018; p. 494. ISBN 978-1-11905383.
47. Azapagic, A.; Bore, J.; Cheserek, B.; Kamunya, S.; Elbehri, A. The global warming potential of production and consumption of Kenyan tea. *J. Clean. Prod.* **2016**, *112*, 4031–4040. [CrossRef]
48. Briceno, T.; Stagl, S. The role of social processes for sustainable consumption. *J. Clean. Prod.* **2006**, *14*, 1541–1551. [CrossRef]
49. Parag, Y. Beyond energy efficiency: A 'prosumer market' as an integrated platform for consumer engagement with the energy system. *Eur. Counc. Energy Effic. Econ. Summer Study* **2015**, *1*, 15–23.
50. Braglia, M.; Petroni, A. Stakeholders influence and internal championing of product stewardship in the Italian food packaging industry. *J. Ind. Ecol.* **2000**, *4*, 75–92. [CrossRef]
51. Carlton, R.; Thompson, H. Product Stewardship—Is there a role for better collaboration? *Outlooks Pest Manag.* **2009**, *20*, 126–127. [CrossRef]
52. Lewis, H. Defining product stewardship and sustainability in the Australian packaging industry. *Environ. Sci. Policy* **2005**, *8*, 45–55. [CrossRef]
53. Neto, A.S.; Jabbour, C.J.C. Guidelines for improving the adoption of cleaner production in companies through attention to non-technical factors: A literature review. *Afr. J. Bus. Manag.* **2010**, *4*, 4217–4229.
54. Stitzhal, D. Product Stewardship: Can it drive green design? *Environ. Qual. Manag.* **2011**, *20*, 25–41. [CrossRef]
55. Schober, A.; Kittel, C.; Baumgartner, R.J.; Füllsack, M. Identifying dominant topics appearing in the Journal of Cleaner Production. *J. Clean. Prod.* **2018**, *190*, 160–168. [CrossRef]
56. Seadon, J.K. Sustainable waste management systems. *J. Clean. Prod.* **2010**, *18*, 1639–1651. [CrossRef]
57. Aarnio, T.; Hämäläinen, A. Challenges in packaging waste management in the fast food industry. *Resour. Conserv. Recycl.* **2008**, *52*, 612–621. [CrossRef]
58. Filimonau, V.; Gherbin, A. An exploratory study of food waste management practices in the UK grocery retail sector. *J. Clean. Prod.* **2017**, *167*, 1184–1194. [CrossRef]
59. de Oliveira Santos, H.; Alves, J.L.S.; Coutinho de Melo, F.J.; Dumke de Medeiros, D. An approach to implement cleaner production in services: Integrating quality management process. *J. Clean. Prod.* **2020**, *246*, 118985. [CrossRef]
60. Sojkin, B.; Ankiel, M. Retail networks as a place of purchase-the example of large cities in Poland. *Acta Sci. Polonorum. Oeconomia* **2019**, *18*, 101–110. [CrossRef]
61. WMA. World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *J. Am. Med. Assoc.* **2013**, *310*, 2191–2194.
62. Convention Bureau Wroclaw. About the City. 2022. Available online: https://convention.wroclaw.pl/about-the-city/ (accessed on 15 November 2022).
63. Fedyk, W.; Sołtysik, M.; Olearnik, J.; Barwicka, K.; Mucha, A. How Overtourism Threatens Large Urban Areas: A Case Study of the City of Wrocław, Poland. *Sustainability* **2020**, *12*, 1783. [CrossRef]
64. Okpala, C.O.R.; Nwobi, O.C.; Korzeniowska, M. Assessing Nigerian Butchers' Knowledge and Perception of Good Hygiene and Storage Practices: A Cattle Slaughterhouse Case Analysis. *Foods* **2021**, *10*, 1165. [CrossRef]
65. Taherdoost, H. Validity and Reliability of the Research Instrument: How to Test the Validation of a Questionnaire/Survey in a Research. *Int. J. Acad. Res. Manag.* **2016**, *5*, 28–36. [CrossRef]
66. Vargha, A.; Delaney, H.D. The Kruskal-Wallis test and stochastic homogeneity. *J. Educ. Behav. Stat.* **1998**, *23*, 170–192. [CrossRef]
67. Chan, Y.; Walmsley, R.P. Learning and understanding the Kruskal-Wallis one-way analysis-of-variance-by-ranks test for differences among three or more independent groups. *Phys. Ther.* **1997**, *77*, 1755–1761. [CrossRef] [PubMed]
68. Okpala, C.O.R.; Korzeniowska, M. Concept, Content, and Context Perspectives of Quality of Agrofood Products: Reflections on Some Consumer Decision-Making-Purchase Scenarios. *Front. Nutr.* **2020**, *7*, 578941. [CrossRef]
69. Okpala, C.O.R.; Korzeniowska, M.; Guiné, R.P.F. Towards managing quality in agro-food technological processes: From people to products. In Proceedings of the Poster Presented at the 9th Quality and Safety in Food Production Chain Conference, Wroclaw, Poland, 15–16 September 2022.
70. Stone, L. When case studies are not enough: The influence of corporate culture and employee attitudes on the success of cleaner production initiatives. *J. Clean. Prod.* **2000**, *8*, 353–359. [CrossRef]

04 czerwca 2023 r

(miejscowość i data)

Charles Odilichukwu R. OKPALA…

Katedra Rozwoju Funkcjonalnych Produktów Żywnościowych

Wydział Biotechnologii i Nauk o Żywności

Uniwersytet Przyrodniczy we Wrocławiu

OŚWIADCZENIE

Oświadczam, że w pracy …… *Okpala, C. O. R. (2023). Good Practices contributing to Cleaner Food Production? A Preliminary Survey Analysis involving Wrocław-Poland Food Retail Sector. Processes 11*(4)*, 1224* …. mój przewodniczył i kierował konceptualizacją, projektowaniem badań eksperymentalnych / terenowych, metodologią badań, administrowaniem projektem, walidacją/wizualizacją danych, a także rozwojem manuskryptu od projektu, przez proces recenzowania, aż do ostatecznej akceptacji pracy do publikacji.

Okpala

04. June 2023……………

data i podpis