Poultry meat quality preservation by plant extracts: an overview

Ines Feknous, Djamal Ait Saada, Cerine Yasmine Boulahlib, Laura Alessandroni, Sendous Wadjila Souidi, Ouiza Ait Chabane, Mohammed Gagaoua

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.54.058
ID: 133248265
https://doi.org/10.18485/meattech.2023.64.3.2

Review paper

Poultry meat quality preservation by plant extracts: an overview

Ines Feknous[1], Djamal Ait Saada[1], Cerine Yasmine Boulahlib[2], Laura Alessandroni[3], Sendous Wadjila Souidi[4], Ouiza Ait Chabane[1] and Mohammed Gagaoua[5]*

[1] *Food Technology and Nutrition Laboratory (LTAN), Abdelhamid Ibn Badis University, 27000, Mostaganem, Algeria*
[2] *Université des Frères Mentouri Constantine, 25000, Constantine, Algeria*
[3] *Chemistry Interdisciplinary Project (CHIP), School of Pharmacy, University of Camerino, Via Madonna delle Carceri, 62032 Camerino, Italy*
[4] *Laboratory of Sciences and Technics of Animal Production, Abdelhamid Ibn Badis University, Mostaganem, 27000, Mostaganem, Algeria*
[5] *PEGASE, INRAE, Institut Agro, 35590 Saint-Gilles, France*

ARTICLE INFO

Keywords:
Chicken meat safety
Plant extracts
Shelf-life
Natural preservatives
Bioactive compounds
Meat preservation

ABSTRACT

Poultry meat is appreciated by consumers for its nutritional value, low fat content, versatility of use in various cuisines and affordable prices. However, its susceptibility to spoilage due to multiple pre-slaughter and processing factors poses challenges for the meat industry, especially in developing countries. To improve the safety of poultry products, synthetic preservatives like nitrites, butylated hydroxytoluene and sulphites are used. Currently, these additives/preservatives have, however, raised concerns about their impact on human health, prompting a shift from consumers toward natural alternatives, such as medicinal and aromatic plants. Therefore, this paper delves into the potential of plant extracts as natural preservatives for improving the quality and shelf-life of chicken meat and processed products. It provides an overview of the various plant extracts and essential oils that have demonstrated antimicrobial, antioxidant and enzyme inhibitory properties, without compromising the sensory attributes of the products. Different incorporation methods are discussed, including direct incorporation or marination in aqueous and/or alcoholic extracts, and the use of essential oils, including for *in vivo* animal feed supplementation. Overall, each method influences the final product quality differently. We further summarised the current knowledge about the mechanisms of action of the plant extracts tested, even though they are not fully elucidated. Despite the benefits of these compounds, some challenges have to be addressed, including standardising the composition of the extracts, harmonising the sensitivity of the bioactive compounds with the processing conditions, ensuring cost effectiveness and obtaining regulatory approvals for their use. The scaling up of production to meet industry demands also presents some technical challenges. Overall, the application of natural plant preservatives not only enhances chicken meat quality, but also could support the meat industry to align with the evolving consumer expectations for sustainable food products.

1. Introduction

Meat, the product of converting animal muscle into a culinary delight, holds immense importance in human diets and cultures worldwide. The transformation of muscle into meat through sophisticated post-mortem physical and biochemical changes that occur in early post-mortem and during ageing, confers the expected sensory qualities by consumers. In fact, meat is rich in essential nutrients, it provides proteins, vitamins and minerals, which all are crucial for human health (*Shah et al.,* 2014; *Geldenhuys et al.,* 2015). Among the various types of meat, poultry stands out for its advantageous nutritional composition that makes it highly valued for healthy dietary practices (*Jilo & Hasan,* 2022). It has a lower fat content in contrast to red meat, and is predomi-

***Corresponding author:** *mohammed.gagaoua@inrae.fr*

Received: October 24th 2023. Corrected November 3rd 2023. Accepted November 2nd 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

nantly composed of unsaturated fatty acids *(Saleh et al., 2020; Hailemariam et al.,* 2022). Overall, chicken meat and derived products are affordable, exempt of religious constraints, and have valuable technological characteristics, making them widely consumed sources of animal proteins (*Liu et al.,* 2012; *Vranić et al.,* 2014).

Despite these numerous advantages, industry is challenged with the fragile character of chicken meat that can alter in 4 to 8 days, owing to the white muscle structure, the overall health state of the animal and slaughter conditions *(Abdel-Salam et al., 2017; Alessandroni et al.,* 2021). The rate of spoilage is furthermore exacerbated by the post-slaughter handling at the retail phase due to cold chain breaks during transport and inappropriate storage temperatures (*Rani et al.,* 2017).

To reduce the economic losses induced by this deterioration and to satisfy the growing demand of the consumers, preservatives like sodium and potassium nitrites, butylated hydroxytoluene (BHT), sulphites and other chemical products are used to stabilise the biochemical and enzymatic processes, inhibit bacterial growth, prevent lipid oxidation reactions and to enhance the colour, flavour and tenderness properties (*Mani-López et al.,* 2016; *Gutiérrez-Del-río et al.,* 2021; *Atwaa et al.,* 2022). Although these chemical (synthetic) compounds are effective in extending the shelf-life of chicken meat with technological benefits and cost conveniences, they are highly questionable and controversial concerning their potential impact on human health (*Thakur et al.,* 2019; *Yu et al.,* 2021). For example, some of them have been deemed allergenic, like sulphites, carcinogenic like butylated hydroxyanisole (BHA) and BHT, or as precursors to carcinogenic components like nitrates and nitrites that react with certain amino acids during high-heat cooking to form nitrosamines *(Drabik-Markiewicz et al.,* 2010; *Muthukumar et al.,* 2020; *Xie et al.,* 2023). Thus, these compounds are no longer desirable due to the growing concerns by consumers over their intake of chemical ingredients in food. In fact, consumers are becoming more proactive about their health and they have place emphasis on products with transparent labelling, reduced or absent synthetic ingredients and minimally processed products, while having more expectations that products are locally sourced and/or of natural origin (*Fox et al.,* 2018*; Mesías et al.,* 2021).

Considering the above concerns, incorporating natural preservatives from plants in chicken meat preservation would then offer a multitude of benefits. For the industry, it provides an eco-friendly alternative to synthetic additives, aligning with the growing demand for more sustainable food production. Using plant-derived preservatives can also reduce production costs and improve supply chain efficiency, ultimately boosting profitability. Moreover, it enhances product quality, reducing food waste, while still ensuring safe and healthy products (*Seidavi et al.,* 2021). For consumers, the impact is profound, as they enjoy chicken products that are free from potentially harmful synthetic additives, resulting in improved food safety and overall well-being. This approach supports a healthier, more sustainable food industry, satisfying both producers and consumers (*Vinci et al.,* 2022; *Pinto et al.,* 2023). These aspects constitute the objectives of this review, which aims to provide an overview of the main plants and their compounds that have been identified to have antioxidant, antimicrobial and enzyme inhibitory properties, used to improve the quality and extend the shelf-life of chicken meat and its derived products. We also discuss the different processes of their incorporation, the mechanisms of action, and the challenges encountered when using natural extracts on muscle food products.

2. An overview of the main plants used for chicken meat preservation

Medicinal and aromatic plants have long been part of the cultural heritage of different ethnicities. They find their place in ancestral medicine, cosmetics and culinary recipes *(Miara et al.,* 2019a; *Miara et al.,* 2019b). In the context of traditional (ethnic) methods of meat preservation, different herbs are used to mask unpleasant or improve the odour and taste, along with increasing the shelf-life of the products (*Gagaoua & Boudechicha,* 2018; *Ez zoubi et al.,* 2022). Broiler meat from battery-farmed chicken presents a mild flavour and subtle taste, sometimes described as bland and insipid by consumers, who prefer local, traditional pasture-raised chicken (*Gnakari et al.,* 2007). However, it has the advantage of easily adapting to different seasonings and absorbing their aroma. This versatility facilitates the incorporation of plants, plant extracts and essential oils as preservatives, thereby enhancing the taste of chicken meat products and prolonging their shelf-life without negative influences on the inherent organoleptic characteristics (*Tian et al.,* 2014 ; *Qi et al.,* 2022).

Table 1. Summary table of key studies and findings regarding plant extract use in chicken meat preservation.

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Basil *(Ocimum basilicum)*	2.5 and 5 mg/ml (solution)	Raw and autoclaved meat	72h – 4°C and 18°C – EO – Sterile petri dishes	• Significant effect on normal flora • Reduction of artificially inoculated *Salmonella enteritidis* • Physicochemical parameters (pH, colour, texture, TBARS, cooking loss) beneficially affected for most of them	(*Stojanović-Radić et al.,* 2018)
Cinnamon *(Cinnamomum verum / cassia)*	0.25, 1 and 2% (w/v) EO	Chicken breast fillets	15 days – 4°C – Nanoemulsion with chitosan-pectin solution	• Strong *in vitro* antimicrobial activity against *L. monocytogenes* and *P. deceptionensis* • EO nanoemulsion improved the pH, oxidative stability, and colour properties of chicken breasts	(*Wang et al.,* 2021)
Cinnamon *(Cinnamomum verum / cassia)*	0.5 % of oil macerate (1g/100ml oil)	Ready-to-eat chicken patties	16 days – 4°C – Gelatine-chitosan nano-emulsion coating infused with EO + sterile polyethylene bags	• Better coating characteristics • Stronger antimicrobial activity • Lowest TVC, pH, TVBN and TBARS • Dramatically reduced moisture loss • Shelf-life extension by more than 4 days	(*Qiu et al.,* 2022)
Coriander *(Coriandrum sativum)*	1%	Chicken patties	9 days – 4°C – Aqueous extract	• Reduction of peroxide, Total carbonyls, metmyoglobin formation • Microbial growth (TPC) inhibited and low TBARS rates • No colour or odour changes after cooking	(*Ahmad et al.,* 2023)
Citrus *(Citrus spp.)*	0.1 and 0.2 ml /100g meat	Fresh ground chicken	14 days – 4°C – LDPE and LDPE/EVOH/LDPE films – Citrox® extract	• Extension of the microbiological shelf-life by 1–2 days (extract alone) and 3–4 days when combined with an O_2 absorber • No significant changes in colour, but positively significant in odour and taste • Physicochemical parameters slightly affected by the different treatments	(*Mexis et al.,* 2012)
Clove *(Syzygium aromaticum)*	0.5 and 1%	Raw chicken meat	15 days – 4°C – LDPE bags – Ethanolic extract	• Highly effective against microbial growth: TVC, LAB, *Enterobacteriaceae* and *Pseudomonas* spp. count • Prevention of lipid oxidation (TBARS) • Good extraction yield, overall acceptability and antioxidant potential: DPPH, FICA • Meat colour preservation	(*Zhang et al.,* 2016); (*Radha Krishnan et al.,* 2014)
Rosemary *(Rosmarinus officinalis))*					

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Rosemary *(Rosmarinus officinalis)*	EO/EtOH 30/70 at different concentrations from 0.1% to 4% w/w	Fresch sliced chicken breast meat	7 days – 4°C – directly sprayed on meat – PET packaging	• Antibacterial action of volatile components of *R. officinalis* extracted by hydrodistillation • BA production inhibition after just 2 days of storage • The antibacterial and anti-BA action was due to the formulation of a new active packaging system with essential oil of *R. officinalis*	(*Sirocchi et al.,* 2013)
Rosemary *(Rosmarinus officinalis)*	EO/tween 80 1% and 2% (w/v) solutions	Fresh minced chicken meat	21 days – 4°C – chitosan/ sodium caseinate – PLA film	• EO films showed antioxidant and inhibition of lipid peroxidation effects: DPPH and TBARS • EO film coated meat reported lower concentrations of heptanal, butanoic acid and ethanol	(*Fiore et al.,* 2021)
Curry *(Murraya kœnigii)*	1%	Restructured chicken slices	20 days – 7±1°C – Leaf powders – LDPE bags	• No significant difference in the cooking yield and proximate composition • Significantly lower microbial counts • No detection of yeast or mould • No significant changes in the sensory parameters, with a good overall acceptability	(*Najeeb et al.,* 2015)
Drumstick *(Moringa oleifera)*					
Mint *(Mentha spp.)*					
Fennel seeds *(Fœniculum vulgare)*	0.2% v/w	Chicken thighs	16 days – 4±0.5°C – EO – Vacuum packaging	• TVC reduction for *Enterobacteriaceae*, *Pseudomonas* spp, LAB • Prolongation of the shelf-life of chicken thighs	(*Kačániová et al.,* 2019)
Savory *(Satureja hortensis)*					
Garlic *(Allium sativum)*	Fresh garlic: 20, 30, 50 g/kg) Ground powder: 6, 9, 15 g/kg) Garlic EO: 0.06, 0.09, 0.15 g/kg)	Raw chicken sausage (thigh meat)	21 days – 3°C – Fresh garlic / garlic powder / garlic EO – Vacuum packaging in polyethylene bags	• Delay of lipid oxidation (TBA) • No changes in the compositional content • Reduction of the microbial count • Sensory results showed a good overall acceptability even though fresh garlic sausages had stronger flavour	(*Sallam et al.,* 2004)
Ginger *(Zingiber officinale)*	3 and 6 %	Chicken breast fillets	12 days – 4°C – EO (nano) emulsion edible coating	• Significant decrease of TPC • Non-significant TBARs effect • Better colour preservation • Lower cooking loss and good overall acceptability	(*Noori et al.,* 2018)
Green tea *(Camellia sinensis)*	0.5 %	Minced chicken breast	200 minutes – Hydroethanolic extract – Vacuum packaging – Freezing then mincing	• Pro-oxidative effect • Less antioxidant than mate	(*Jongberg et al.,* 2019)
Mate *(Ilex paraguariensis)*	0.01%, 0.05, 0.1 and 0.5 %			• No reaction with protein thiols in chicken meat • Direct dose-dependent response: protection of the protein thiols	

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Hawthorn *(Crataegus pinnatifida)*	0.5 and 1%	Cooked chicken breast meat	150, 200 and 250°C then overnight storage at 4°C	• Mitigation of HAA formation, especially at high cooking temperatures • No negative changes in structure, appearance, colour and odour	(*Tengilimoglu-Metin et al.,* 2017)
Laurel bay *(Laurus nobilis)*	1%	Fresh raw chicken breast slices	16 days – 4±1°C – Ethanolic extract – Sterile plastic bags	• Significant decrease in chemical parameters (pH, TBVN, TBA) • Marked decrease in bacterial counts (aerobic plate, total *coliform*, and total *Staphylococci* count) • Extension of the chicken meat shelf-life	(*Youssef et al.,* 2021)
Olive leaf *(Olea europaea)*	0.25, 0.5 and 1%	Raw poultry meat	15 days – 4±1°C – Plastic bags – Ethanolic extract	• Reduction of microbial growth (TABC, TPC, TEC, TSC and Total Mould and Yeast Count) • Preservation of chemical (pH, TVBN, TBARS) and sensory attributes • Good antioxidant effect and overall acceptability	(*Saleh et al.,* 2020)
Oregano *(Origanum vulgare)*	Glycerol, EO, N,O-carboxymethyl chitosan and EO/ N,O-carboxymethyl chitosan water solutions	Chicken breast fillets	14 days – 4°C	• EO and N,O-carboxymethyl chitosan used individually, showed a significant antibacterial and preservative effect • EO/ N,O-carboxymethyl chitosan combination resulted to a 6 day shelf-life extension of chicken fillets	(*Khanjari et al.,* 2013)
Oregano *(Origanum vulgare)*	5g EO /100g nanoemulsion	Chicken pâté	45 days – Nanoemulsion encapsulation – Pasteurisation in hot water bath and ambient temperature storage	• Good antimicrobial growth: low values of MIC and MBC on *E. coli* and *S. aureus* • No significant change in physicochemical properties of meat (moisture, protein, ash, fat, pH)	(*Moraes-Lovison et al.,* 2017)
Pepper seeds *(Piper annuum)*	1 % powder and 7% oil	Chicken sausages	14 days – 100°C for 30mn then 4°C ± 1°C – Cellulose casing and PVDC bags – Powder and EO	• Retarded lipid oxidation (lower TBARS values) • Sensory attributes and nutritional value favourably affected • No textural properties change, except for hardness decrease	(*Kim,* 2020)
Pomegranate *(Punica granatum)*	Pomegranate juice phenolics 8ml /100g meat Powder extract phenolics 1ml / 100g meat	Cooked chicken patties	15 days – 4°C – Rind powder and aqueous extract – Aerobic packaging in LDPE pouches	• Better protection against oxidative rancidity (TBARs) than BHT used as positive control • Total phenolic compounds increased in the final product • No negative effect on the sensory attributes	(*Naveena et al.,* 2008)

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Sage *(Salvia officinalis)*	0.2% w/w	Cooked chicken thigh and breast	96h – 4°C – Polyester film – Marinade and heating	• Lower TBARS values → Protection from oxidation processes • Increasing in moisture content • Great consumer acceptability	(*Sampaio et al.,* 2012)
Thyme *(Thymus vulgaris)*	0.05 wt/vol of EO blend	Fresh raw marinated chicken meat (Breast and wings)	12 days – +4°C Marinade with EO blend	• High lipid oxidation prevention potential (TBARS) • No pH, colour, shear force, moisture, cooking yield, purge loss or marinade uptake changes	(*Rimini et al.,* 2014)
		Frozen raw marinated chicken meat (Breast and wings)	90 days – -18°C – Marinade with EO blend		
Turmeric *(Curcuma longa)*	0.5 and 1%	Cooked chicken breast meatballs	4h at 4°C then 18mn cooking at 150, 200 and 250°C – Turmeric powder	• Dose-dependent inhibition of the heterocyclic aromatic amines (HAA) formation • Reduction of the cooking loss and the lipid oxidation • Preservation of colour properties	(*Kilic et al.,* 2021)

BA: Biogenic Amine – BHT : Butylated Hydroxytoluene – DPPH: 2,2-Diphenyl 1-picrylhydrazyle – EO: Essential Oil – EVOH: Ethylene Vinyl Alcohol – FICA: Ferrous Ion Chelating Activity – HAA: Heterocyclic Aromatic Amines – LAB: Lactic Acid Bacteria – LDPE: Low Density Polyethylene – MBC: Minimum Bactericidal Concentration – MIC: Minimum Inhibitory Concentration – PET: Polyethylene Terephthalate – PLA: Polylactic Acid – PVDC: Poly Vinylidene Chloride – TBA: Thiobarbituric Acid – TBARS: Thiobarbituric Acid Reactive Substances – TEC: Total Enterobacteriaceae Count – TPC: Total Psychrophilic Count – TSC: Total Staphylococcal Count – TVBN: Total Volatile Basic Nitrogen – TVC: Total Viable Count.

Table 1 offers a comprehensive overview of the plant extracts tested and added in different forms to improve and preserve the quality of chicken meat products and details their impacts on the products. The studies reported significant antimicrobial and antioxidant potential of the plants used. Furthermore, most of the studies evidenced positive impacts on the physicochemical, sensorial and nutritional properties of chicken meat products. It is noteworthy that the recovery of the extracts depends on the targeted bioactive compounds and the type or part of the plant. Furthermore, the aerial plant parts, encompassing fruits, leaves, flowers, and bark, serve as primary sources (*Kicel et al.,* 2019; *Polka & Podsędek,* 2019). In some bulbs and rhizomes like turmeric and ginger, the emphasis lies in their underground parts (*Elmowalid et al.,* 2019; *Kilic et al.,* 2021). Seeds and roots can be also used (*Melloul et al.,* 2022; *Sharma et al.,* 2023). A relatively new way to extract plant phytochemicals, significant due to reduced costs and less waste generation, is the valorisation of industry by-products rather than non-by-product plant materials. By-products include pomaces from the processing of tomato (seeds and peels), grape (seeds, skins and stems) and olive (skin, pulp, kernels and oil residue), which showed interesting biological activities and promising preservation abilities for meat products (*Gutiérrez-Del-río et al.,* 2021). Overall, it has been observed that the inclusion of plant extracts in the formulation and preparation of chicken meat products do not compromise the sensory properties or overall acceptability as assessed by sensory panellists (*Mohd Subakir et al.,* 2022; *Zhu et al.,* 2022). The following sections delve into these details and discuss some examples of the different plant extracts that have been incorporated as natural chicken meat preservatives.

3. Plant extracts and incorporation strategies

Several techniques for incorporating plant-based components into chicken meat and its derived products have been evaluated, which taken all together aimed to extend product shelf-life while improving or preserving product quality. These approaches encompass the utilisation of raw plant material and various forms of extracts as natural food additives in meat preparations during processing, as well as in the form of dietary supplements in animal feed during breeding.

3.1. Direct incorporation

Direct incorporation is a simple application, low cost, and does not require specific equipment or reagents. The plant material can be spread fresh or powdered onto chicken meat products. For instance, *Sallam et al.* (2004) added fresh or dried garlic cloves to raw chicken sausages, *Kilic et al.* (2021) incorporated powdered turmeric into chicken meatballs, *Najeeb et al.* (2015) tested powders of drumstick leaves, curry, and mint on restructured chicken slices, and *Kim* (2020) formulated chicken sausages enriched with pepper seed powder.

To strengthen the efficacy of phytochemicals, marination encompasses immersing chicken meat in a solution infused with aromatic plants, spices and other ingredients (*İncili et al.,* 2020). This approach solubilises the plant compounds, thereby increasing their availability to preserve meat, enhances the organoleptic properties, likely tenderness and juiciness, and reduces the cooking loss (*Sampaio et al.,* 2012; *Rimini et al.,* 2014; *Lytou et al.,* 2018; *Wu et al.,* 2019). Aqueous extracts can be further used. For example, the application of aqueous extracts of coriander and pomegranate rind powder has been reported by *Ahmad et al.* (2023) and *Naveena et al.* (2008). Aqueous extraction consists of soaking different parts of the plant in hot or cold water for a specified time, filtrating to discard the solid retentate and eventually reduce the liquid through evaporation and/or lyophilisation. Water has the ability to dissolve a wide range of compounds, and different biocomponents can be recovered depending on the adopted heating method: decoction, infusion or maceration (*Rahim et al.,* 2022).

3.2. Alcoholic and hydroethanolic extracts

Ethanol is less harmful than most other organic solvents and is the most recommended for food applications. The combination of water and alcohol allows the extraction of a larger group of compounds compared to using the solvents individually (*Alzeer & Abou Hadeed,* 2016; *Tobiszewski & Namieśnik,* 2017). Rosemary and clove hydroethanolic extracts, along with olive leaf ethanolic extract have been used as additives and revealed better preservative properties (increased shelf-life) of raw poultry meat stored at 4°C for 15 days (*Zhang et al.,* 2016; *Saleh et al.,* 2020). Laurel bay leaf ethanolic extract allowed 16 days of preservation for the same product and under the same conditions (*Youssef et al.,* 2021). It is noteworthy that the extraction yield and composition of the plant extracts depend on the chosen method and the variations in the time-temperature regime used. Conventional extraction methods such as maceration, digestion, percolation and Soxhlet, are effective in extracting most secondary metabolites of plants and are simple to replicate. However, these extraction methods are only adapted to small-scale batch production and involve several time and solvent-consuming steps (*Bitwell et al.,* 2023). Thus, developing environmentally friendly innovative methods that are adapted to large-scale production and that are economically viable are keystones in modern phytochemistry research. Newer methods have emerged, like accelerated solvent extraction, microwave assisted extraction, ultrasound assisted extraction (sonication) (*Nayak et al.,* 2015), supercritical fluid extraction (*Caredda et al.,* 2002), enzyme assisted extraction (*Rafińska et al.,* 2022), pressurised hot water extraction and deep eutectic solvents (*Loarce et al.,* 2021; *Liao et al.,* 2022).

3.3. Essential oils

Essential oils are obtained by hydro-distillation and are added directly as ingredients in chicken meat preparations; for this purpose, essential oils of fennel seeds, pepper seeds, garlic, basil, and rosemary are used (*Sallam et al.,* 2004; *Stojanović-Radić et al.,* 2018; *Kačániová et al.,* 2019; *Kim,* 2020). The oils can also be encapsulated to preserve their odours and flavours, protect them from degradation and likely improve their stability. In fact, encapsulation seemed to increase the bioavailability of essential oils by preserving them from degradation, especially by gastric acids (*Zhang et al.,* 2022; *Zhang & Piao,* 2023). Innovative techniques, such as nanoemulsions of essential oils and synergistic incorporation into packaging and edible coatings, is another way of improving their preservative properties (*Sirocchi et al.,* 2013; *Moraes-Lovison et al.,* 2017; *Noori et al.,* 2018; *Gagaoua et al.,* 2021; *Qiu et al.,* 2022).

3.4. Indirect incorporation

Innovative techniques such as nano-emulsions of essential oils and synergistic incorporation of plant extracts into packaging and edible coatings represent green approaches to improve chicken meat quality preservation while reducing or eliminating the strong odours and flavours of some aromatic plants (*Sirocchi et al.,* 2013; *Moraes-Lovison et al.,* 2017; *Noori et al.,* 2018; *Gagaoua et al.,* 2021; *Qiu et al.,* 2022). In this context, several approaches have been explored. For example, a coating made of a synergistic blend of propolis extract and chitosan, enriched with *Zataria multiflora* essential oil revealed substantial antimicrobial and antioxidant effect, while enhancing chemical characteristics and sensory acceptability of chicken breast meat (*Mehdizadeh & Mojaddar Langroodi,* 2019). Phenolic extracts of petioles from betel leaf have been also used to develop a sustainable, biodegradable, functional antioxidant film, successfully maintaining raw chicken meat quality for up to 12 days at refrigeration temperature (*Nandi & Guha,* 2024). In another study, lower values of pH, thiobarbituric acid reactive substances (TBARS) and total microbe counts after five days of storage were observed in chicken samples packed in carrageenan-based films fortified with medicinal plant extracts (*Seol et al.,* 2013). *Jacob Rani & Venkatachalam* (2023) conducted a study on poultry meat packaging with a chitosan-based active coating, synergised with nanoparticles synthesised from cellulose, hemicellulose and lignin from leaves of the abundant invasive plant, cattail (*Typha latifolia)*. The coating exhibited good antioxidant and antimicrobial activities due to the phenolic properties of the plant extracts, and so subsequently extended the shelf-life of the product. These few studies exemplified the potential for incorporating plant extracts with the aim of reducing wastage and improving the freshness and sensory qualities of chicken products.

3.5. In vivo feed supplementation

An alternative strategy regarding the use of plants to enhance the quality of chicken meat and increase its nutritional value is the inclusion of specific medicinal and aromatic plants in the animal diet as feed supplements (*Giannenas et al.,* 2020; *Jin et al.,* 2020; *Mohebodini et al.,* 2021). Phenolic compounds can be adopted to combat infectious agents as alternatives to antibiotics that can lead to resistance phenomena in animals with possible transmission to humans (*Mahfuz et al.,* 2021). The growth performance of battery and ground-raised broilers, evaluated by the measurement of the body weight gain and the consumption index, was significantly ameliorated after broilers were fed with green oak acorns (*Berkane et al.,* 2021). Dietary addition of oregano and germander for instance, decreased lipid oxidation, monitored by TBARS assay and total carbonyl values, leading to a storage duration of seven days (*Al-Hijazeen et al.,* 2022). Feed supplementation with thyme oil decreased the saturated fatty acid content of poultry meat and increased the unsaturated fatty acids, with unchanged TBARS values for 42 days at refrigeration temperature (*Canan Bölükbaşı & Erhan,* 2006).

4. Effects and mechanisms of action of plant extracts in chicken meat and processed products

4.1. Antimicrobial potential

Plant extracts have been proven to be valuable in reducing microbial growth in chicken meat. For instance, pomegranate juice marinades were able to delay the microbial growth of *Pseudomonas* spp., *Enterobacteriaceae*, *Brochothrix thermosphacta* and lactic acid bacteria (LAB) for 6 to 9 days at 4°C and 10°C on chicken breast fillets (*Lytou et al.,* 2018). The synergistic action of oregano essential oil and chitosan coating diminished *Pseudomonas deceptionensis* CM2 and bacteria total viable count (TVC) in chicken breast fillets stored in refrigerated conditions for 12 days (*Zheng et al.,* 2023). Citrox®, a commercial citrus extract also showed a positive effect on the reduction of the TVC, *Pseudomonas*, *Enterobacteriaceae*, LAB, and *Clostridium* spp., and prolonged the shelf-life of fresh ground chicken refrigerated at 4°C (*Mexis et al.,* 2012).

The mechanisms of action of plant extracts and essential oils against bacteria are intricate and multifaceted. They vary depending on the diverse plant constituents, type of microorganisms, and strains. These mechanisms are not completely elucidated yet, but the commonly known ones that can be enumerated as follows:

- *Cell membrane disruption:* Cell wall thickening is a significant pathway to antibiotic resistance in bacteria. Polyphenols, flavonoids and other bioactive compounds counteract it by compromising the membrane fluidity, rendering it permeable, and cell death occurs by leakage of the cytoplasmic content (*Weng et al.,* 2023). Flavonoids for instance, can interfere with lipid bilayers by inducing bacterial membrane disruption, which inhibits processes such as biofilm formation, cell envelope synthesis, and nucleic acid synthesis (*Górniak et al.,* 2019).
- *Efflux pumps inhibitors (EPIs):* Efflux pumps are membrane proteins maintaining cell homeostasis through active efflux. In bacteria, they are involved in (multi)drug resistance

mechanisms (*Kumawat et al.,* 2023). Numerous plant species have demonstrated their potential to inhibit these pumps and disturb the inner metabolism of Gram-positive and Gram-negative strains (*Seukep et al.,* 2020; *Brown et al.,* 2021; *Mehta et al.,* 2022).

- *Quorum sensing interference:* Quorum sensing is a paracrine cellular signalling system by which bacteria interact with each other and with their environment (*Thompson et al.,* 2023). Perturbing this process alters the genetic expression of virulence determinants and reduces the formation of biofilms (*Ivanov et al.,* 2022; *Kumawat et al.,* 2023).

These control modes not only reduce bacterial count and inhibit multiplication, but also reinstate antibiotic efficacy (*Ivanov et al.,* 2022). Other mechanisms such as oxygen quenching, the inhibition of enzyme activity, damage to DNA, ribosomes or mitochondria, protein denaturation, and induction of oxidative stress by reactive oxygen species (ROS) are other pathways that have been described in the literature (*Rout et al.,* 2022).

4.2. Antioxidant potential

Oxidation is the second most important degradation form after microbial spoilage of chicken meat, and of meat products in general (*Domínguez et al.,* 2019). In fact, oxidation leads to changes in several meat quality traits, like colour, taste and flavour. In fact, development of lipid rancidity leads to undesirable taste and flavour. The colour change is more noticeable on chicken thigh meat cuts, due to the physiological specifications of poultry, as pH and myoglobin content are higher in this cut and different from in the breast (*Wideman et al.,* 2016). Oxidative deterioration also alters the nutritional value by the loss of proteins and vitamins, along with the generation of toxic compounds (*Domínguez et al.,* 2019; *Dursun & Güler,* 2023). In this context, several plant extracts, which exhibited a strong antioxidant activity, were tested on chicken meat with the aim to increase its shelf-life and improve its nutritional quality. Rosemary, oregano, pomegranate, olive leaf and clove showed effectiveness in drastically reducing TBARS values, interpreted as a superior protection against oxidative rancidity of chicken meat lipids, even better than some synthetic preservatives like BHT (*Al-Hijazeen,* 2022; *Naveena et al.,* 2008; *Saleh et al.,* 2020; *Zhang et al.,* 2016).

Aromatic plants are rich in polyphenols and flavonoids that prevent oxidative damage in meat by forming multiple coordinate bonds with pro-oxidative compounds (*Gutiérrez-Del-río et al.,* 2021; *Pateiro et al.,* 2021). These bioactive compounds act as hydrogen atom donators, metallic ions chelators, ferrous reducing agents or radical scavengers by decomposing ROS species like hydrogen peroxide $H_2O_2^{\bullet}$ and superoxide anion $O_2^{-\bullet}$. These various mechanisms of action impede the oxidation reactions, neutralise free radicals and reduce lipid oxidation by lowering the production of peroxide molecules (*Köksal et al.,* 2017; *Yan et al.,* 2020).

4.3. Enzyme regulatory potential

When the animal is slaughtered oxygen and glucose delivery to cells are no longer active, therefore leading to dysregulated muscle homeostasis (*Ouali et al.,* 2013). The complex processes of post-mortem transformation of muscle into meat are initiated, and sophisticated biochemical reactions in the carcass are triggered (*Terlouw et al.,* 2021; *Lamri et al.,* 2023). Such pathways lead to the production of ROS. In this matter, polyphenols would act on the regulation of certain pathways and enzymes, such as NADH oxidase, by inhibiting ROS formation, thereby breaking the oxidation chain reaction (*Yan et al.,* 2020). They can also upregulate endogenous antioxidant enzymes like superoxide dismutase, catalase and glutathione peroxidase.

4.4. Preservation of physicochemical and sensory properties of meat

The correlation between the underlying mechanisms of action of plant extracts and the preservation of the physicochemical properties of chicken meat has been established from the foregoing discussed research results:

- The regulation of enzymes in the tenderisation process and scavenging ROS formation seemed to have a direct impact on the meat texture. For instance, meat from chicken fed with oregano essential oil has lower Warner-Bratzler (WB) shear force values (*Mahfuz et al.,* 2021). Improvements in the water holding capacity of the meat increases the cooking yield and decreases the purge loss, leading to a better meat tenderness and juiciness (*Zheng et al.,* 2023).

- Inhibiting lipid oxidation prevents the development of a rancid taste in meat. Furthermore, essential oils and aromatic compounds in the extracts allow the development of new aromas and flavours in chicken meat products, resulting generally in good overall acceptability by consumers (*Munekata et al.,* 2015; *Hadidi et al.,* 2022).
- Colour is influenced, among other factors, by exposure to oxygen, storage temperatures, and anatomical location of the meat cuts that affects the pH balance and the concentration of myoglobin (*Wideman et al.,* 2016). Packed chicken meat in edible coatings enriched with essential oils or sprayed on the surface with phenolic extracts promoted the oxygenation of myoglobin to form oxymyoglobin, which gives the bright, vivid, light pink hue to chicken meat, and inhibits myoglobin's oxidation to metmyoglobin, thus preserving the visual appeal of the meat (Figure 1) (*Gagaoua et al*., 2021; *Zhou et al*., 2021; *Wu et al*., 2022).

4.5. Nutritional value enhancement

Even though the primary objective for which plant extracts and essential oils are used in food as natural preservatives is for their antioxidant and antimicrobial effects, they still contribute indirectly to the preservation and enhancement of the nutritional content of the food. The antioxidant effects of polyphenols and terpenoids, along with iron sequestration by flavonoids preserve for instance, polyunsaturated fatty acids (PUFA), like omega-3 fatty acids (*Tang et al.,* 2002; *Gutiérrez-Del-río et al.,* 2021). Consuming food products enriched with aromatic plants increases the daily intake of polyphenols, known for their beneficial effects on health (*Fraga et al.,* 2010; *Vauzour et al.,* 2010; *Tresserra-Rimbau et al.,* 2018). Figure 1 depicts a few of the preservation effects of plant extracts on chicken meat.

5. Plant compounds involved in chicken meat quality preservation and/or improvement

Secondary metabolites, which originate mainly from defence reactions against environmental threats, exhibit unique and specific activities through distinct mechanisms, contributing to their importance in a variety of applications (*Gutiérrez-Del-río et al.,* 2021). The secondary metabolites that derive from primary metabolites during plant development have been the subject of much attention in the literature due to their structural diversity and properties, highlighting their importance in medicinal and culinary applications (*Twaij & Hasan*, 2022). Owing to the wide range of compounds that exist in the vegetal realm, all their differences, and in the absence of a universal classification, each author

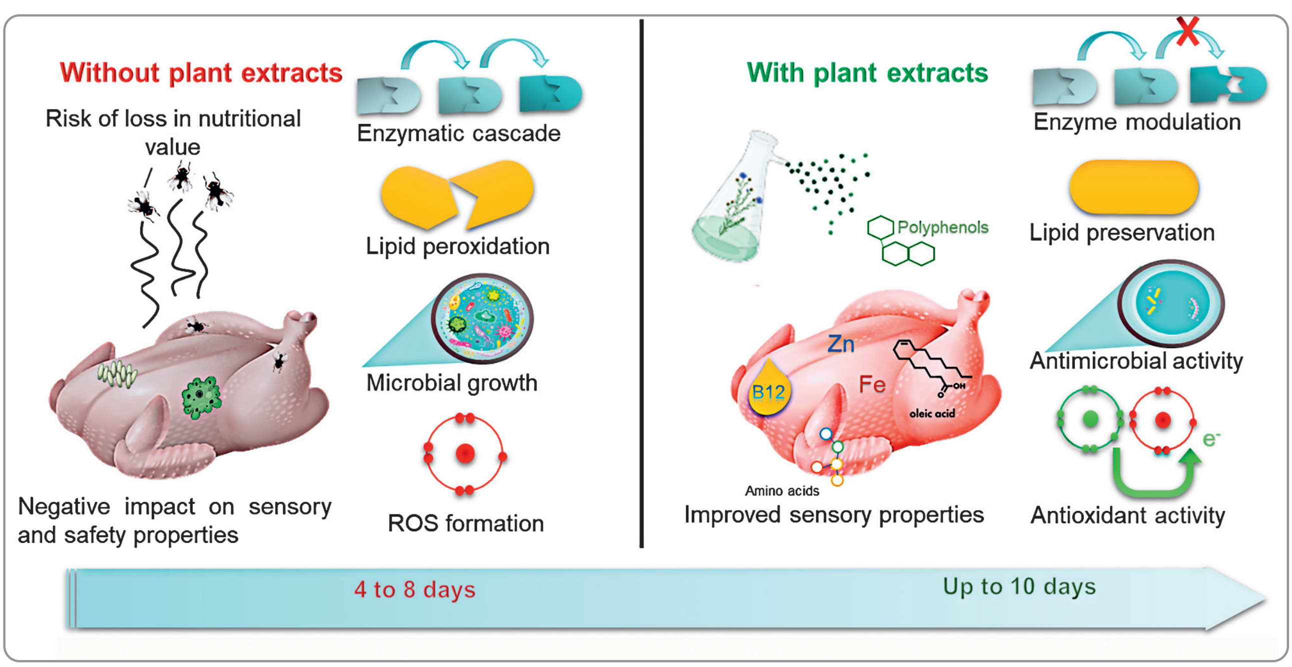

Figure 1. Visual illustration highlighting the positive impacts of chicken meat preservation that can be achieved with plant extracts.

sorts them according to their own study aims. For instance, *Arvind* (2016) used a classification based on the chemical composition: alkaloids, glycosides, polyphenols (flavonoids, phenolics and tannins), saponins, terpenes (carotenoids and steroids) and anthraquinones. *Ahmed et al.* (2017) referred to the British Nutrition Foundation that divides them into four categories: terpenoids, phenolics, nitrogen containing compounds and sulphur containing compounds, while *Kabera et al.* (2014) used a more generic classification system of three major groups: terpenoids, alkaloids and phenolics. Some of these various plant metabolites are particularly appreciated in the preservation of muscle foods according to *Biswas et al.* (2023) and are described in-depth in the following sections.

5.1. Polyphenols

Polyphenols are abundant in fruits, vegetables and herbs. They act as powerful antioxidants and antimicrobials when incorporated into meat products (*Wu & Zhou,* 2021; *Biswas et al.,* 2023). The ability of phenolic compounds to act as antioxidants relies on the quantity and location of hydroxylic groups within their structure, as these factors determine their effectiveness in neutralising reactive radicals. Consequently, polymers with an elevated concentration of hydroxylic groups exhibit a greater antioxidant capacity (*Oliveira et al.,* 2018). For example, pepper fruits (*Capsicum* spp.), one of the most widely used and appreciated spices in the world for their spiciness and unique flavours, are rich in phenolic compounds such as capsaicinoids, luteolin and quercetin (*Batiha et al.,* 2020a). An earlier study has shown that capsiate, dihydrocapsiate and their analogues possess very high antioxidant activity (*Rosa et al.,* 2002). Clove (*Syzygium aromaticum*) is another traditional spice used for food preservation, particularly in meat processing where it can replace chemical preservatives due to its antioxidant and antibacterial properties (*Cortés-Rojas et al.,* 2014; *Batiha et al.,* 2020b). Clove has been documented as a significant source of phenolic compounds, as it contains hydroxybenzoic, ferulic, caffeic, ellagic and salicylic acids (*Cortés-Rojas et al.,* 2014). Garlic (*Allium sativum* L.) is a well-known bulb in traditional medicine and culinary preparations, including traditional meat products (*Gagaoua & Boudechicha,* 2018). It is rich in phenols and various sulphur phytoconstituents such as alliin, allicin, ajoenes, vinyldithiins. It has been successfully evaluated for its various biological activities, including antibacterial, antiviral, antifungal, antiprotozoal and antioxidant (*Batiha et al.,* 2020b).

5.2. Flavonoids

Flavonoids are another class of plant compounds known for their antioxidant and antibacterial activities (*Dias et al.,* 2021). In fact, more than 6000 different flavonoids have been identified in plants so far (*Hichri et al.,* 2011). They are abundant in green plants, and are present mainly as glycosides in leaves, flowers, stems and roots (*Chen et al.,* 2023). Flavonoids' antioxidant capacities are modulated by the location of the catechol B-ring on the pyran C-ring, along with the quantity and arrangement of hydroxylic groups present on the catechol group within the B-ring (*Dias et al.,* 2021). Cloves for instance, contain quercetin and kaempferol (*Thomas et al.,* 2022). Moreover, multiple studies indicate that garlic, rich in flavonoids, phenols and various sulphur compounds, exhibits strong radical-scavenging activity (*Jang et al.,* 2017), and the antibacterial activity of these phytochemicals is linked to different pathways (*Górniak et al.,* 2019).

5.3. Terpenes

Terpenes are the main compounds of essential oils and are biologically generated by the mevalonate pathway (*Dhifi et al.,* 2016). From the molecular level viewpoint, they are constituted from 2-methylbuta-1,3-diene carbon structures, also known as isoprene units. These units are capable of being reordered into cyclic structures, thus explaining the important structural diversity of this group (*Hyldgaard et al.,* 2012; *Masyita et al.,* 2022). Terpenes are easily identified and classified by the number of isoprene units in their carbon skeleton (*Twaij & Hasan,* 2022). Terpenes play an important role in food safety without affecting food quality (*Falleh et al.,* 2020). Terpenes such as thymol, carvacrol and eugenol are found in essential oil of thyme, oregano, rosemary, and clove. They have been proven to possess antimicrobial properties (*Mendonca et al.,* 2018; *Bellés et al.,* 2019). Clove flower buds contain up to 18% essential oil composed of eugenol, eugenol acetate and β-cariofilene (*Jirovetz et al.,* 2006). An earlier study demonstrated the antimicrobial efficacy of essential oils from several spices: cinnamon, thyme, rosemary, garlic, sage, oregano, basil, marjoram, savory and clove (*Mendonca et* *al.,* 2018). Other studies further tested successfully the antibacterial efficacy of thyme and rosemary essential oils at very low concentrations against a mix of three strains of *Listeria monocytogenes* (*Giarratana et al.,* 2016). Moreover, others have shown that thyme, bay leaf, oregano and clove essential oils exhibit varying degrees of inhibition against *Escherichia coli* (*Thielmann et al.,* 2019).

6. Practical considerations for implementing plant extracts as meat preservatives

Natural bioactive compounds have clearly proven their effectiveness in reducing microbial growth, preventing oxidation, and enhancing the organoleptic properties of meat, including poultry. Nevertheless, some factors hinder their successful utilisation and pose challenges to their widespread industrial application for reducing chicken meat deterioration and for prolonging the shelf-life. In the following, we discuss some of the practical considerations that are worthy of consideration in order to avoid drawbacks associated with their use.

6.1. Determination of the composition and concentration of plant extracts

The composition and concentration of the bioactive compounds of plant extracts are not consistent across all sources and batches, and vary even for the same plant species according to growing conditions, harvest time and season, extraction settings, storage conditions and packaging methods (*Oluyemisi Folashade et al.,* 2012; *Tajik et al.,* 2014; *Pferschy-Wenzig & Bauer*, 2015). These result in unpredictable synergistic and antagonistic interactions between the extract compounds themselves, or between the extract compounds and the chicken meat matrix. These interactions can affect the stability of the extracts and their antioxidant and antimicrobial activity (*Lu et al.,* 2017; *Woroń & Siwek,* 2018; *Nguyen & Karboune,* 2023). Therefore, the standardisation and determination of the effective concentration are even more challenging: underdosage reduces the potency of the extract while too high concentrations may lead to unpleasant sensory changes and formulation issues, introducing unfamiliar textures or flavours, thus affecting the consumer acceptability of the final product. In the meat matrix, the presence of fatty acids, proteins and other components can favour these changes when reacting with the compounds of the plant extracts. Finding the right balance between preservation efficacy and sensory acceptability is crucial and a key challenge (*Lu et al.,* 2017; *Skochko et al.,* 2018; *Barbieri et al.,* 2019; *Sajad et al.,* 2020). Moreover, during the preparation of these additives, other interfering molecules or compounds can be extracted from the plant, making a purification step necessary. Purification techniques have made significant advancements in recent years and appear to address these issues effectively on an experimental level. However, the feasibility for industrial-scale implementation remains limited due to the associated high costs and the substantial equipment it necessitates (*Weil & Veraitch,* 2014; *Folim,* 2015).

6.2. Regulatory and safety aspects

Due to the complex composition of plant extracts, their use as food preservatives is conditioned by strict national and/or international standards and is under regulatory compliance. This is even more important when it comes to the determination of the concentration to be used in meat products, due to the nature of meat constituents and how they react with phytochemicals (*Alirezalu et al.,* 2020; *Biswas et al.,* 2023). As depicted in Figure 2, plant extracts are susceptible to diverse environmental contaminants, including pesticides, waterborne chemicals, synthetic drugs and heavy metals (*Han et al.,* 2016; *Kostic et al.,* 2019). Moreover, the native bacterial microbiota of plants can pose risks to human health, like mycotoxins from fungi or thermoresistant toxins from sporulating bacteria (*Omotayo et al.,* 2019; *Alirezalu et al.,* 2020). Genetic cross contamination within plant species is an inevitable occurrence, whether it involves organic or heirloom plants intermingling, or crossing paths with genetically modified crops. Such interactions can yield unexpected outcomes or the introduction of undisclosed compounds, such as allergens, toxins and even opioids, thereby complicating the contamination landscape (*Geller et al.,* 2015; *Cau et al.,* 2021). This intricate web of cross-contamination highlights the need for meticulous monitoring and regulation within the agricultural industry to ensure the safety and integrity of food supply (*Steier,* 2016).

Even though legal frameworks and directives can vary between countries, the safety and efficacy of the natural preservatives must be demonstrated in order to obtain regulatory acceptance. For instance, in the United States, the Food and Drug Administration (FDA) maintains a list of generally recognised as

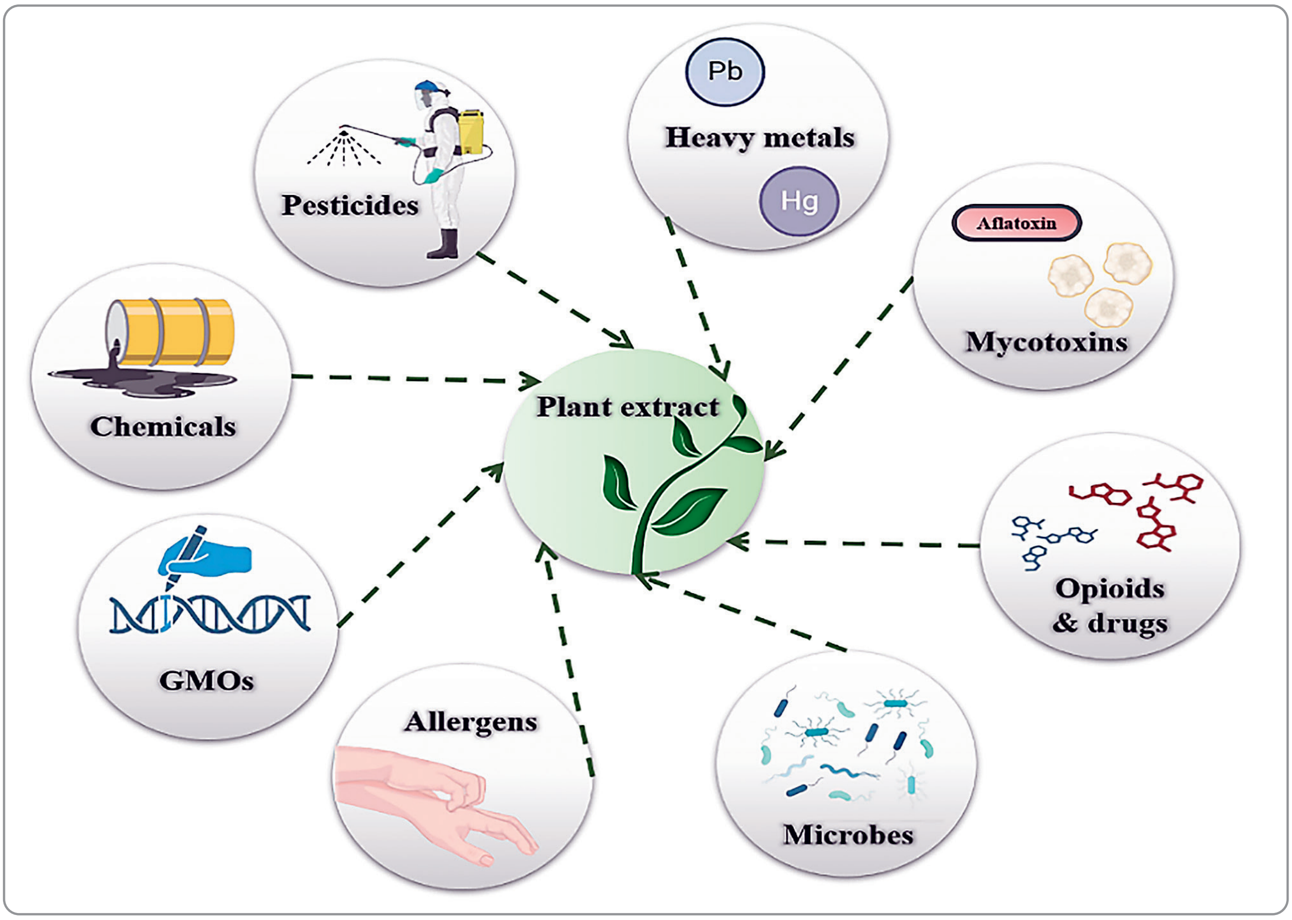

Figure 2. Safety hazards that can be associated with plant extract usage.

safe (GRAS) essential oils that can be used in meat products (*Khaneghah et al.,* 2017). In the European Union, the Regulation 1129/2011 prescribes permissible compounds and their limited doses in various food products, considering the composition of the product, and whether or not it will undergo thermal treatment (*Alirezalu et al.,* 2020). Regulation EU 1169/2011 also sets out the legal obligation to declare known allergens, like celery, sesame or soy (*Cau et al.,* 2021).

6.3. Bioavailability and intestinal absorption

When added to chicken meat, extracts from medicinal and aromatic plants have roles in the preservation of the product before consumption and the improvement of the product's sensory attributes (*Muhialdin et al.,* 2020; *Hassan et al.,* 2022). Polyphenols, the main secondary metabolites of plants, have seen greater consumption popularity in recent decades, causing a significant increase in the demand for polyphenol-enriched products. Selling arguments advocating the beneficial effects on the human body after ingestion, and even describing the products enriched with polyphenols as "superfood" contributed greatly to the development of this new dietary trend (*Fernández-Ríos et al.,* 2022). While plant components have shown their antioxidant, antimicrobial and enzyme regulatory efficacy as well as their contribution to reduce several diseases, scientists describe it as a marketing gimmick and are more sceptical about the real impact of polyphenols on the human body when ingested in food. This scepticism comes from the fact that the bioavailability and efficacy of consuming polyphenols in food are hardly predictable, and are influenced by a wide range of variables (*Tresserra-Rimbau et al.,* 2018). We believe that much work in this area is needed in the future.

6.4. Cost considerations

The cost of plant extract production and commercialisation is higher than for synthetic preservatives. The latter are cheaper due to their longer shelf-life, stability and mass-production adaptability. Therefore, scaling up the production of plant extracts to meet the demands of the food industry can present logistical challenges (*Surekha & Reddy,* 2014; *Vara et al.,* 2019). As a matter of fact, sourcing ingredients for natural preservative production is conditioned by the seasonality of plants and their geographical availability, causing supply chain complexations. Furthermore, import/export taxes, certification and labelling costs inflate the bill (*Balasubramaniam et al.,* 2022). The production plans have to be studied in depth and adapted to the current regulations and recommendations (*Lee & Paik,* 2016). For instance, the EU REACH Regulation (*EU*, 2006) on registration, evaluation, authorisation and restriction of chemicals strongly encourages the adoption of eco-friendly "green" solvents as alternatives to conventional organic ones. The selection of one solvent over another is a strategic decision, since it affects the extraction method, compound selectivity, production yield, costs and safety (*Pateiro et al.,* 2021). While multiple environmentally friendly extraction techniques have emerged at experimental level in scientific literature, the acquisition of avant-garde technologies has a cost. Moreover, the type of extract can present another drawback. A typical case in point would be the use of essential oils in food preservation. Otherwise indisputably effective as antioxidants and antimicrobials, essential oils are hydrophobic, rendering their solubilisation very technical; they are highly concentrated in volatile compounds, resulting in strong off-odours and aromas; and have a considerably low extractability and extraction yield (*Al-Refaie et al.,* 2023). Given these conditions, the production cost of using essential oils in chicken meat production is thus elevated (*Bouarab Chibane et al.,* 2019).

7. Conclusion

From this review, we can conclude that investigations of the utilisation of plant extracts to preserve chicken meat and its processed meat products have yielded a promising avenue for prolonging the shelf-life duration. This review highlighted the plant extracts that have rich composition in diverse groups of bioactive compounds, which confer strong microbial growth mitigation and enzyme inhibition, and prevent lipid and protein oxidation. They also can enhance the organoleptic and sensory properties of chicken meat products. However, the use of plant-based preservatives at an industrial scale faces some challenges, including standardisation, regulatory approval, sensory acceptability, and cost-effectiveness. Moreover, in the scientific literature, we have noticed a gap regarding chicken meat quality preservation in comparison to other meat species (mainly red meat products), and most existing studies only pulverise the surface, focusing on the antioxidant and antimicrobial effects using manual, conventional methods, without delving deeper into a better understanding of the underlying mechanisms or identifying the specific compounds involved in the preservation process. To overcome these challenges, it is necessary to initiate further interdisciplinary research efforts that combine principles from food science, biochemistry and biotechnology. For instance, omic approaches unravel complex molecular factors influencing chicken meat quality and could offer a holistic view to understand and predict quality changes during storage (*Wang et al.,* 2023). Furthermore, high-throughput screening through appropriate design of experiments can efficiently identify the potential extract/compound candidates, while microbiome analysis can clarify interactions of the compounds with chicken meat-associated microorganisms. Additionally, nanotechnology is another promising discipline that contributes to the optimisation of encapsulation and emulsion, with prominent uses in meat research (*Lamri et al.,* 2021). Nano-techniques protect the extracts from degradation during storage and guarantee suitable meat quality preservation without introducing the strong aromas of certain plant extracts into the meat products. In addition, nanotechnology can enable controlled release of the extracts, which in turn, increases the bioavailability and intestinal absorption of high value compounds like polyphenols and flavonoids from chicken meat-enriched products. Cutting-edge green processes for recovering natural compounds from plants are also highly regarded in the scientific community. For example, approaches such as supercritical fluid extraction, ultrasound extraction or microwave assisted extraction, coupled with the use of eco-friendly solvents like deep eutectic and ionic solvents demonstrate environmental responsibility and offer promising alternatives to the traditional extraction methods that use organic solvents, known to be toxic and polluting. Overall, the adoption of plant-based natural preservatives not only aligns with the clean label and health-conscious preferences of consumers, but also contributes to the sustainability of the meat industry by reducing its environmental impacts.

Očuvanje kvaliteta mesa živine biljnim ekstraktima: pregledni rad

Ines Feknous, Djamal Ait Saada, Cerine Yasmine Boulahlib, Laura Alessandroni, Sendous Wadjila Souidi, Ouiza Ait Chabane i Mohammed Gagaoua

INFORMACIJE O RADU

Ključne reči:
Bezbednost pilećeg mesa
Biljni ekstrakti
Rok upotrebe
Prirodni konzervansi
Bioaktivna jedinjenja
Konzervisanje mesa

APSTRAKT

Potrošači cene meso živine zbog njegove nutritivne vrednosti, niskog sadržaja masti, raznovrsnosti upotrebe u raznim kuhinjama i pristupačnih cena. Međutim, njegova podložnost kvarenju kao posledice više faktora pre klanja i prerade predstavlja izazov za industriju mesa, posebno u zemljama u razvoju. Da bi se poboljšala bezbednost živinskih proizvoda, koriste se sintetički konzervansi kao što su nitriti, butilovani hidroksitoluen i sulfiti. Trenutno, ovi aditivi/konzervansi, međutim, izazvaju zabrinutost zbog njihovog uticaja na zdravlje ljudi, što je dovelo do pomeranja kod potrošača na prirodne alternative, kao što su lekovite i aromatične biljke. Stoga se ovaj rad bavi potencijalom biljnih ekstrakata kao prirodnih konzervansa za poboljšanje kvaliteta i roka trajanja pilećeg mesa i prerađevina. Ovaj rad pruža pregled različitih biljnih ekstrakata i eteričnih ulja koja su pokazala antimikrobna, antioksidativna i inhibitorna svojstva enzima, bez ugrožavanja senzornih atributa proizvoda. Razmatraju se različite metode inkorporacije, uključujući direktnu inkorporaciju ili mariniranje u vodene i/ili alkoholne ekstrakte, i upotrebu eteričnih ulja, uključujući in vivo suplementaciju stočnom hranom. Sve u svemu, svaka metoda različito utiče na kvalitet finalnog proizvoda. Dalje smo sumirali sadašnja saznanja o mehanizmima delovanja testiranih biljnih ekstrakata, iako nisu u potpunosti razjašnjeni. Uprkos prednostima ovih jedinjenja, potrebno je rešiti neke izazove, uključujući standardizaciju sastava ekstrakata, usklađivanje osetljivosti bioaktivnih jedinjenja sa uslovima obrade, obezbeđivanje isplativosti i dobijanje regulatornih odobrenja za njihovu upotrebu. Povećanje proizvodnje u cilju zadovoljavanja potreba industrije takođe predstavlja neke tehničke izazove. Sve u svemu, primena prirodnih biljnih konzervansa ne samo da poboljšava kvalitet pilećeg mesa, već bi takođe mogla da podrži mesnu industriju u smislu uskladjivanja sa očekivanjima potrošača u razvoju za održive prehrambene proizvode.

Disclosure statement: No potential conflic of interest was reported by authors.

References

Abdel-Salam, Z., Abdel-Salam, S. A. M. & Harith, M. A. (2017). Application of Laser Spectrochemical Analytical Techniques to Follow Up Spoilage of White Meat in Chicken. *Food Analytical Methods*, 10 (7), 2365–2372, https://doi.org/10.1007/S12161-017-0806-5

Ahmad, A., Mahmood, N., Hussain, M., Aiman, U., Al-Mijalli, S. H., Raza, M. A. & Al Jbawi, E. (2023). Improvement in oxidative stability and quality characteristics of functional chicken meat product supplemented with aqueous coriander extract. *International Journal of Food Properties*, 26 (1), 855–865, https://doi.org/10.1080/10942912.2023.2189086

Ahmed, E., Arshad, M., Zakriyya Khan, M., Shoaib Amjad, M., Mehreen Sadaf, H., Riaz, I., Sidra Sabir, P., Ahmad, N., Sabaoon, P., Correspondence Ejaz Ahmed, P. & Sabir, S. (2017). Secondary metabolites and their multidimensional prospective in plant life. *~ 205 ~ Journal of Pharmacognosy and Phytochemistry*, 6 (2), 205–214.

Alessandroni, L., Caprioli, G., Faiella, F., Fiorini, D., Galli, R., Huang, X., Marinelli, G., Nzekoue, A. F., Ricciutelli, M., Scortichini, S., Silvi, S., Tao, J., Tramontano, A., Turati, D. & Sagratini, G. (2021). A shelf-life study for the evaluation of a new biopackaging to preserve the quality of organic chicken meat. *Food Chemistry*, 371, 131134, https://doi.org/10.1016/j.foodchem.2021.131134

Al-Hijazeen, M. (2022). The combination effect of adding rosemary extract and oregano essential oil on ground chicken meat quality. *Food Science and Technology (Brazil)*, 42, https://doi.org/10.1590/fst.57120

Al-Hijazeen, M. A., AL-Rawashdeh, M. S. & Al-Rabadi, G. J. (2022). Cooked broiler meat quality affected by different Mediterranean medicinal plants in the diet. *Animal Bioscience*, 35 (2), 290–298, https://doi.org/10.5713/ab.21.0264

Alirezalu, K., Pateiro, M., Yaghoubi, M., Alirezalu, A., Peighambardoust, S. H. & Lorenzo, J. M. (2020). Phytochemical constituents, advanced extraction technologies and techno-functional properties of selected Mediterranean plants for use in meat products. A comprehensive review. In *Trends in*

Food Science and Technology (Vol. 100, pp. 292–306). Elsevier Ltd, https://doi.org/10.1016/j.tifs.2020.04.010

Al-Refaie, D., Mehyar, G. & Shahein, M. (2023). Functional Role of Essential Oils as Antimicrobial and Antioxidant Agents in Food Industry: A Review. *Jordan Journal of Agricultural Sciences*, 19, 70–88, https://doi.org/10.35516/jjas.v19i1.1237

Alzeer, J. & Abou Hadeed, K. (2016). Ethanol and its Halal status in food industries. *Trends in Food Science & Technology*, 58, 14–20, https://doi.org/https://doi.org/10.1016/j.tifs.2016.10.018

Arvind, K. S. (2016). Medicinal plants: Future source of new drugs. *International Journal of Herbal Medicine*, 4 (4), 59–64, https://doi.org/10.13140/RG.2.1.1395.6085

Atwaa, E., Shahein, M., Radwan, H., Mohammed, N., Aloraini, M., Albezrah, N., Alharbi, M., Adam, H., Daoud, M. & Elmahallawy, E. (2022). Antimicrobial Activity of Some Plant Extracts and Their Applications in Homemade Tomato Paste and Pasteurized Cow Milk as Natural Preservatives. *Fermentation*, 8, 428, https://doi.org/10.3390/fermentation8090428

Balasubramaniam, V. G., Ramakrishnan, S. R. & Antony, U. (2022). Chapter 13 — Opportunities and challenges of plant extracts in food industry. In S. A. Mir, A. Manickavasagan & M. A. Shah (Eds.), *Plant Extracts: Applications in the Food Industry* (pp. 295–315). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-822475-5.00002-8

Barbieri, G., Bergamaschi, M., Saccani, G., Caruso, G., Santangelo, A., Tulumello, R., Vibhute, B. & Barbieri, G. (2019). Processed meat and polyphenols: Opportunities, advantages, and difficulties. *Journal of AOAC International*, 102 (5), 1401–1406, https://doi.org/10.5740/jaoacint.19-0134

Batiha, G. E. S., Alqahtani, A., Ojo, O. A., Shaheen, H. M., Wasef, L., Elzeiny, M., Ismail, M., Shalaby, M., Murata, T., Zaragoza-Bastida, A., Rivero-Perez, N., Beshbishy, A. M., Kasozi, K. I., Jeandet, P. & Hetta, H. F. (2020a). Biological properties, bioactive constituents, and pharmacokinetics of some capsicum spp. and capsaicinoids. In *International Journal of Molecular Sciences* (Vol. 21, Issue 15, pp. 1–35). MDPI AG, https://doi.org/10.3390/ijms21155179

Batiha, G. E. S., Alkazmi, L. M., Wasef, L. G., Beshbishy, A. M., Nadwa, E. H. & Rashwan, E. K. (2020b). Syzygium aromaticum l. (myrtaceae): Traditional uses, bioactive chemical constituents, pharmacological and toxicological activities. In *Biomolecules* (Vol. 10, Issue 2). MDPI AG, https://doi.org/10.3390/biom10020202

Bellés, M., Alonso, V., Roncalés, P. & Beltrán, J. A. (2019). Sulfite-free lamb burger meat: antimicrobial and antioxidant properties of green tea and carvacrol. *Journal of the Science of Food and Agriculture*, 99 (1), 464–472, https://doi.org/10.1002/jsfa.9208

Berkane, F., Bouderoua, k., Ait Saada, D., & Selselet-Attou, G. (2021). Effects of Green Oaks Acorns (*Quercus ilex*) based Diets Added of Calcium Bentonite on Health of Broilers Reared in the Cages and Ground Modes. *Research Journal of Agronomy*, 15 (2), 7–11, https://doi.org/10.18805/IJAR.BF-1487

Biswas, O., Kandasamy, P., Nanda, P. K., Biswas, S., Lorenzo, J. M., Das, A., Alessandroni, L., Lamri, M., Das, A. K. & Gagaoua, M. (2023). Phytochemicals as natural additives for quality preservation and improvement of muscle foods: a focus on fish and fish products. *Food Materials Research*, 3 (1), 0–0, https://doi.org/10.48130/fmr-2023-0005

Bitwell, C., Indra, S. Sen, Luke, C. & Kakoma, M. K. (2023). A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants. *Scientific African*, 19, e01585, https://doi.org/https://doi.org/10.1016/j.sciaf.2023.e01585

Bouarab Chibane, L., Degraeve, P., Ferhout, H., Bouajila, J. & Oulahal, N. (2019). Plant antimicrobial polyphenols as potential natural food preservatives. *Journal of the Science of Food and Agriculture*, 99 (4), pp. 1457–1474, https://doi.org/10.1002/jsfa.9357

Brown, A. R., Ettefagh, K. A., Todd, D. A., Cole, P. S., Egan, J. M., Foil, D. H., Lacey, E. P. & Cech, N. B. (2021). Bacterial efflux inhibitors are widely distributed in land plants. *Journal of Ethnopharmacology*, 267, 113533, https://doi.org/https://doi.org/10.1016/j.jep.2020.113533

Canan Bölükbaşı, Ş. & Erhan, M. (2006). Effect of dietary thyme oil and vitamin E on growth, lipid oxidation, meat fatty acid composition and serum lipoproteins of broilers, http://www.sasas.co.za/sajas.asp

Caredda, A., Marongiu, B., Porcedda, S. & Soro, C. (2002). Supercritical carbon dioxide extraction and characterization of Laurus nobilis essential oil. *Journal of Agricultural and Food Chemistry*, https://doi.org/10.1021/jf0108563

Cau, S., Tilocca, M. G., Spanu, C., Soro, B., Tedde, T., Salza, S., Melillo, R., Piras, G., Virgilio, S., Vodret, B. & Mudadu, A. G. (2021). Detection of celery (Apium graveolens) allergen in foods of animal and plant origin by droplet digital PCR assay. *Food Control*, 130, 108407, https://doi.org/https://doi.org/10.1016/j.foodcont.2021.108407

Chen, S., Wang, X., Cheng, Y., Gao, H. & Chen, X. (2023). A Review of Classification, Biosynthesis, Biological Activities and Potential Applications of Flavonoids. In *Molecules* (Vol. 28, Issue 13). Multidisciplinary Digital Publishing Institute (MDPI), https://doi.org/10.3390/molecules28134982

Cortés-Rojas, D. F., de Souza, C. R. F. & Oliveira, W. P. (2014). Clove (Syzygium aromaticum): a precious spice. *Asian Pacific Journal of Tropical Biomedicine*, 4 (2), 90–96, https://doi.org/https://doi.org/10.1016/S2221-1691(14)60215-X

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N. & Mnif, W. (2016). Essential Oils' Chemical Characterization and Investigation of Some Biological Activities: A Critical Review. *Medicines*, 3 (4), 25, https://doi.org/10.3390/medicines3040025

Dias, M. C., Pinto, D. C. G. A. & Silva, A. M. S. (2021). Plant flavonoids: Chemical characteristics and biological activity. *Molecules*, 26 (17), https://doi.org/10.3390/molecules26175377

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W. & Lorenzo, J. M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, 8 (0), MDPI, https://doi.org/10.3390/antiox8100429

Drabik-Markiewicz, G., Dejaegher, B., De Mey, E., Impens, S., Kowalska, T., Paelinck, H. & Vander Heyden, Y. (2010). Evaluation of the influence of proline, hydroxyproline or pyrrolidine in the presence of sodium nitrite on N-nitrosamine formation when heating cured meat. *Analytica Chimica Acta*, 657 (2), 123–130, https://doi.org/10.1016/j.aca.2009.10.028

Dursun, A. & Güler, Z. (2023). Colour and pigment in raw ground meat incorporated crushed garlic during the refrigerated storage: Their relationship to lipolytic and volatilomic changes. *Food Chemistry*, 419, https://doi.org/10.1016/j.foodchem.2023.136042

Elmowalid, G. A., Abd El-Hamid, M. I., Abd El-Wahab, A. M., Atta, M., Abd El-Naser, G. & Attia, A. M. (2019). Garlic and ginger extracts modulated broiler chicks innate immune responses and enhanced multidrug resistant Escherichia coli O78 clearance. *Comparative Immunology, Microbiology and Infectious Diseases*, 66, https://doi.org/10.1016/j.cimid.2019.101334

Falleh, H., Ben Jemaa, M., Saada, M. & Ksouri, R. (2020). Essential oils: A promising eco-friendly food preservative. *Food Chemistry*, 330, 127268, https://doi.org/https://doi.org/10.1016/j.foodchem.2020.127268

Fernández-Ríos, A., Laso, J., Hoehn, D., Amo-Setién, F. J., Abajas-Bustillo, R., Ortego, C., Fullana-i-Palmer, P., Bala, A., Batlle-Bayer, L., Balcells, M., Puig, R., Aldaco, R. & Margallo, M. (2022). A critical review of superfoods from a holistic nutritional and environmental approach. *Journal of Cleaner Production*, 379, https://doi.org/10.1016/j.jclepro.2022.134491

Ferreira V. C., Morcuende D., Hérnandez-López S. H., Madruga M. S., Silva F. A. & Estévez M. (2017). Antioxidant Extracts from Acorns (Quercus ilex L.) Effectively Protect Ready-to-Eat (RTE) Chicken Patties Irrespective of Packaging Atmosphere. *Journal of Food Science* 82, 622–31, DOI: 10.1111/1750-3841.13640.

Fiore, A., Park, S., Volpe, S., Torrieri, E., & Masi, P. (2021). Active packaging based on PLA and chitosan-caseinate enriched rosemary essential oil coating for fresh minced chicken breast application. *Food Packaging and Shelf Life*, 29, https://doi.org/10.1016/j.fpsl.2021.100708

Folim, G. H. (2015). *Purification columns and methods* (Patent No. US 2015/0258469 A1). Patent Application Publication, https://eureka.patsnap.com/pdfnew/?patentId=1fc03d46-86b4-498f-b5e9-e3a1c16b6f72

Fox, M., Mitchell, M., Dean, M., Elliott, C. & Campbell, K. (2018). The seafood supply chain from a fraudulent perspective. In *Food Security* (Vol. 10, Issue 4, pp. 939–963). Springer Netherlands, https://doi.org/10.1007/s12571-018-0826-z

Fraga, C. G., Galleano, M., Verstraeten, S. V. & Oteiza, P. I. (2010). Basic biochemical mechanisms behind the health benefits of polyphenols. In *Molecular Aspects of Medicine* (Vol. 31, Issue 6, pp. 435–445), https://doi.org/10.1016/j.mam.2010.09.006

Gagaoua, M., Bhattacharya, T., Lamri, M., Oz, F., Dib, A., Öz, E., Uysal Unalan, I. & Tomasevic, I. (2021). Green Coating Polymers in Meat Preservation. *Coatings*, 11, 1379, https://doi.org/10.3390/coatings11111379

Gagaoua, M. & Boudechicha, H. R. (2018). Ethnic meat products of the North African and Mediterranean countries: An overview. In *Journal of Ethnic Foods* (Vol. 5, Issue 2, pp. 83–98). Elsevier B.V, https://doi.org/10.1016/j.jef.2018.02.004

Geldenhuys, G., Hoffman, L. C. & Muller, N. (2015). The fatty acid, amino acid, and mineral composition of Egyptian goose meat as affected by season, gender, and portion. *Poultry Science*, 94 (5), 1075–1087, https://doi.org/10.3382/ps/pev083

Geller, A. I., Shehab, N., Weidle, N. J., Lovegrove, M. C., Wolpert, B. J., Timbo, B. B., Mozersky, R. P. & Budnitz, D. S. (2015). Emergency Department Visits for Adverse Events Related to Dietary Supplements. *New England Journal of Medicine*, 373 (16), 1531–1540, https://doi.org/10.1056/nejmsa1504267

Giannenas, I., Sidiropoulou, E., Bonos, E., Christaki, E. & Florou-Paneri, P. (2020). Chapter 1 — The history of herbs, medicinal and aromatic plants, and their extracts: Past, current situation and future perspectives. In P. Florou-Paneri, E. Christaki & I. Giannenas (Eds.), *Feed Additives* (pp. 1–18). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-814700-9.00001-7

Giarratana, F., Muscolino, D., Ragonese, C., Beninati, C., Sciarrone, D., Ziino, G., Mondello, L., Giuffrida, A. & Panebianco, A. (2016). Antimicrobial activity of combined thyme and rosemary essential oils against *Listeria monocytogenes* in Italian mortadella packaged in modified atmosphere: Thyme & Rosemary EOs vs L. monocytogenes. *Journal of Essential Oil Research*, 28 (6), 467–474, https://doi.org/10.1080/10412905.2016.1165744

Gnakari, D., Grah, B. & Adouko, A. (2007). Croissance corporelle et qualité organoleptique de la viande du poulet de chair et du poulet africain et leurs croisements en Côte d'Ivoire. In *Livestock Research for Rural Development* (Vol. 19, Issue 5).

Górniak, I., Bartoszewski, R. & Króliczewski, J. (2019). Comprehensive review of antimicrobial activities of plant flavonoids. In *Phytochemistry Reviews* (Vol. 18, Issue 1, pp. 241–272). Springer Netherlands, https://doi.org/10.1007/s11101-018-9591-z

Gutiérrez-Del-río, I., López-Ibáñez, S., Magadán-Corpas, P., Fernández-Calleja, L., Pérez-Valero, Á., Tuñón-Granda, M., Miguélez, E. M., Villar, C. J. & Lombó, F. (2021). Terpenoids and polyphenols as natural antioxidant agents in food preservation. *Antioxidants*, 10 (8), MDPI, https://doi.org/10.3390/antiox10081264

Hadidi, M., Orellana-Palacios, J. C., Aghababaei, F., Gonzalez-Serrano, D. J., Moreno, A. & Lorenzo, J. M. (2022). Plant by-product antioxidants: Control of protein-lipid oxidation in meat and meat products. *LWT*, 169, Academic Press, https://doi.org/10.1016/j.lwt.2022.114003

Hailemariam, A., Esatu, W., Abegaz, S., Urge, M., Assefa, G. & Dessie, T. (2022). Nutritional composition and sensory characteristics of breast meat from different chickens. *Applied Food Research*, 2 (2), https://doi.org/10.1016/j.afres.2022.100233

Han, L., Sapozhnikova, Y. & Matarrita, J. (2016). Evaluation of a new carbon/zirconia-based sorbent for the cleanup of food extracts in multiclass analysis of pesticides and environmental contaminants. *Journal of Separation Science*, 39, https://doi.org/10.1002/jssc.201600920

Hassan, A. H. A., Korany, A. M., Zeinhom, M. M. A., Mohamed, D. Sh. & Abdel-Atty, N. S. (2022). Effect of chitosan-gelatin coating fortified with papaya leaves and thyme extract on quality and shelf life of chicken breast fillet and Kareish cheese during chilled storage. *International Journal of Food Microbiology*, 371, 109667, https://doi.org/https://doi.org/10.1016/j.ijfoodmicro.2022.109667

Hichri, I., Barrieu, F., Bogs, J., Kappel, C., Delrot, S. & Lauvergeat, V. (2011). Recent advances in the transcriptional regulation of the flavonoid biosynthetic pathway. In *Journal of Experimental Botany* (Vol. 62, Issue 8, pp. 2465–2483), https://doi.org/10.1093/jxb/erq442

Hyldgaard, M., Mygind, T. & Meyer, R. L. (2012). Essential oils in food preservation: Mode of action, synergies, and interactions with food matrix components. *Frontiers in Microbiology*, 3 (JAN), https://doi.org/10.3389/fmicb.2012.00012

İncili, G. K., Akgöl, M., Aydemir, M. E., Alan, S., Mutlu, M., İlhak, O. İ. & Öksüztepe, G. (2020). Fate of Listeria monocytogenes and Salmonella Typhimurium in homemade marinade and on marinated chicken drumsticks, wings and breast meat. *LWT*, 134, https://doi.org/10.1016/j.lwt.2020.110231

Ivanov, M., Kostić, M., Stojković, D. & Soković, M. (2022). Rosmarinic acid–Modes of antimicrobial and antibiofilm activities of common plant polyphenol. *South African Journal of Botany*, 146, 521–527, https://doi.org/10.1016/j.sajb.2021.11.050

Jacob Rani B.S. & Venkatachalam S. (2023). Unleashing the potential of bio-nanoparticles from invasive cattail as reinforcement in packaging film to extend the shelf life of poultry meat. Packaging Technology and Science n/a DOI: https://doi.org/10.1002/pts.2773

Jilo, S. A. & Hasan, L. A. (2022). The Importance of Poultry Meat in Medicine: A Review. *Journal of World's Poultry Research*, 12 (4), 258–262, https://doi.org/10.36380/jwpr.2022.28

Jin, L.-Z., Dersjant-Li, Y. & Giannenas, I. (2020). Chapter 10 — Application of aromatic plants and their extracts in diets of broiler chickens. In P. Florou-Paneri, E. Christaki & I. Giannenas (Eds.), *Feed Additives* (pp. 159–185). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-814700-9.00010-8

Jirovetz, L., Buchbauer, G., Stoilova, I., Stoyanova, A., Krastanov, A. & Schmidt, E. (2006). Chemical Composition and Antioxidant Properties of Clove Leaf Essential Oil. *Journal of Agricultural and Food Chemistry*, 54 (17), 6303–6307, https://doi.org/10.1021/jf060608c

Jongberg, S., Racanicci, A. M. C., & Skibsted, L. H. (2019). Mate extract is superior to green tea extract in the protection against chicken meat protein thiol oxidation. Food Chemistry, 300, https://doi.org/10.1016/j.foodchem.2019.125134

Kabera, J. N., Semana, E., Mussa, A. R. & He, X. (2014). Plant Secondary Metabolites: Biosynthesis, Classification, Function and Pharmacological Properties. In *Journal of Pharmacy and Pharmacology* (Vol. 2).

Kačániová, M., Mellen, M., Vukovic, N. L., Kluz, M., Puchalski, C., Haščík, P. & Kunová, S. (2019). Combined effect of vacuum packaging, fennel and savory essential oil treatment on the quality of chicken thighs. *Microorganisms*, 7 (5), https://doi.org/10.3390/microorganisms7050134

Khaneghah, A. M., Hashemi, S. M. B. & Sant'Ana, A. de S. (2017). Essential Oils in Food Processing. In *Essential Oils in Food Processing* (pp. i–xviii). Wiley, https://doi.org/10.1002/9781119149392.fmatter

Khanjari, A., Karabagias, I. K., & Kontominas, M. G. (2013). Combined effect of N,O-carboxymethyl chitosan and oregano essential oil to extend shelf life and control Listeria monocytogenes in raw chicken meat fillets. *LWT — Food Science and Technology*, 53 (1), 94–99, https://doi.org/https://doi.org/10.1016/j.lwt.2013.02.012

Kicel, A., Owczarek, A., Gralak, P., Ciszewski, P. & Olszewska, M. A. (2019). Polyphenolic profile, antioxidant activity, and pro-inflammatory enzymes inhibition of leaves, flowers, bark and fruits of Cotoneaster integerrimus: A comparative study. *Phytochemistry Letters*, 30, 349–355, https://doi.org/https://doi.org/10.1016/j.phytol.2019.02.027

Kilic, S., Oz, E. & Oz, F. (2021). Effect of turmeric on the reduction of heterocyclic aromatic amines and quality of chicken meatballs. *Food Control*, 128, https://doi.org/10.1016/j.foodcont.2021.108189

Kim, Y. K. (2020). Quality improvement of the chicken sausage with pepper seed (Capsicum annuum l.). *Current Research in Nutrition and Food Science*, 8 (3), 829–836, https://doi.org/10.12944/CRNFSJ.8.3.14

Köksal, E., Bursal, E., Gülçin, İ., Korkmaz, M., Çağlayan, C., Gören, A. C. & Alwasel, S. H. (2017). Antioxidant activity and polyphenol content of Turkish thyme (Thymus vulgaris) monitored by liquid chromatography and tandem mass spectrometry. *International Journal of Food Properties*, 20 (3), 514–525, https://doi.org/10.1080/10942912.2016.1168438

Kostic, D., Arsic, B., Ranđelović, S., Pavlović, A., Tošić, S. & Stojanović, G. (2019). Correlation Analysis of Heavy Metals Contents of Malva sylvestris L. plant and Its Extracts from Polluted and Non-polluted Locations in Niš, Republic of Serbia. *Water, Air, & Soil Pollution*, 230, https://doi.org/10.1007/s11270-019-4153-6

Kumawat, M., Nabi, B., Daswani, M., Viquar, I., Pal, N., Sharma, P., Tiwari, S., Sarma, D. K., Shubham, S. & Kumar, M. (2023). Role of bacterial efflux pump proteins in antibiotic resistance across microbial species. In *Microbial Pathogenesis* (Vol. 181). Academic Press, https://doi.org/10.1016/j.micpath.2023.106182

Lamri, M., Bhattacharya, T., Boukid, F., Chentir, I., Dib, A. L., Das, D., Djenane, D. & Gagaoua, M. (2021). Nanotechnology as a processing and packaging tool to improve meat quality and safety. In *Foods* (Vol. 10, Issue 11). MDPI, https://doi.org/10.3390/foods10112633

Lamri, M., della Malva, A., Djenane, D., Albenzio, M. & Gagaoua, M. (2023). First insights into the dynamic protein changes in goat Semitendinosus muscle during the post-mortem period using high-throughput proteomics. *Meat Science*, 202, https://doi.org/10.1016/j.meatsci.2023.109207

Lee, N. K. & Paik, H. D. (2016). Status, antimicrobial mechanism, and regulation of natural preservatives in livestock food systems. In *Korean Journal for Food Science of Animal Resources* (Vol. 36, Issue 4, pp. 547–557). Korean Society for Food Science of Animal Resources, https://doi.org/10.5851/kosfa.2016.36.4.547

Liao, M., Zhao, Y., Yang, X., Yang, L., Liu, E.-H., Lu, B., Wang, J., Liu, X., Chang, Y. & Duan, L. (2022). A greener and sustainable route for medicinal plant analysis: Recycle utilization of hydrophobic deep eutectic solvent. *Microchemical Journal*, 178, 107372, https://doi.org/https://doi.org/10.1016/j.microc.2022.107372

Liu, X. De, Jayasena, D. D., Jung, Y., Jung, S., Kang, B. S., Heo, K. N., Lee, J. H. & Jo, C. (2012). Differential proteome analysis of breast and thigh muscles between Korean native chickens and commercial broilers. *Asian-Australasian Journal of Animal Sciences*, 25 (6), 895–902, https://doi.org/10.5713/ajas.2011.11374

Loarce, L., Oliver-Simancas, R., Marchante, L., Díaz-Maroto, M. C. & Alañón, M. E. (2021). Modifiers based on natural deep eutectic mixtures to enhance anthocyanins isolation from grape pomace by pressurized hot water extraction. *LWT*, 149, 111889, https://doi.org/https://doi.org/10.1016/j.lwt.2021.111889

Lu, H., Lu, Z., Li, X., Li, G., Qiao, Y., Borris, R. P. & Zhang, Y. (2017). Interactions of 172 plant extracts with human organic anion transporter 1 (SLC22A6) and 3 (SLC22A8): A study on herb-drug interactions. *PeerJ*, 2017 (5), https://doi.org/10.7717/peerj.3333

Lytou, A. E., Nychas, G. J. E. & Panagou, E. Z. (2018). Effect of pomegranate based marinades on the microbiological, chemical and sensory quality of chicken meat: A metabolomics approach. *International Journal of Food Microbiology*, 267, 42–53, https://doi.org/10.1016/j.ijfoodmicro.2017.12.023

Mahfuz, S., Shang, Q. & Piao, X. (2021). Phenolic compounds as natural feed additives in poultry and swine diets: a review. In *Journal of Animal Science and Biotechnology* (Vol. 12, Issue 1). BioMed Central Ltd, https://doi.org/10.1186/s40104-021-00565-3

Mani-López, E., Palou, E. & López-Malo, A. (2016). Preservatives: Classifications and Analysis. *Encyclopedia of Food and Health*, https://doi.org/10.1016/B978-0-12-384947-2.00567-5

Masyita, A., Mustika Sari, R., Dwi Astuti, A., Yasir, B., Rahma Rumata, N., Emran, T. Bin, Nainu, F. & Simal-Gandara, J. (2022). Terpenes and terpenoids as main bioactive compounds of essential oils, their roles in human health and potential application as natural food preservatives. *Food Chemistry: X*, 13, https://doi.org/10.1016/j.fochx.2022.100217

Mehdizadeh T. & Mojaddar Langroodi A. (2019). Chitosan coatings incorporated with propolis extract and Zataria multiflora Boiss oil for active packaging of chicken breast meat. *International Journal of Biological Macromolecules* 141, 401–409, DOI: https://doi.org/10.1016/j.ijbiomac.2019.08.267.

Mehta, J., Rolta, R. & Dev, K. (2022). Role of medicinal plants from North Western Himalayas as an efflux pump inhibitor against MDR AcrAB-TolC Salmonella enterica serovar typhimurium: In vitro and In silico studies. *Journal of Ethnopharmacology*, 282, 114589, https://doi.org/https://doi.org/10.1016/j.jep.2021.114589

Melloul, S., Zehioua, R. & Meniai, A.-H. (2022). Supercritical CO2 extraction of bioactive compounds from local Peganum Harmala plant seeds and optimization of the extraction yield and the antioxidant activities. *Sustainable Chemistry and Pharmacy*, 28, 100729, https://doi.org/https://doi.org/10.1016/j.scp.2022.100729

Mendonca, A., Jackson-Davis, A., Moutiq, R. & Thomas-Popo, E. (2018). Use of Natural Antimicrobials of Plant Origin to Improve the Microbiological Safety of Foods. In *Food and Feed Safety Systems and Analysis* (pp. 249–272). Elsevier, https://doi.org/10.1016/B978-0-12-811835-1.00014-2

Mesías, F. J., Martín, A. & Hernández, A. (2021). Consumers' growing appetite for natural foods: Perceptions towards the use of natural preservatives in fresh fruit. *Food Research International*, 150, https://doi.org/10.1016/j.foodres.2021.110749

Mexis, S. F., Chouliara, E. & Kontominas, M. G. (2012). Shelf life extension of ground chicken meat using an oxygen absorber and a citrus extract. *LWT*, 49 (1), 21–27, https://doi.org/10.1016/j.lwt.2012.04.012

Miara, M. D., Bendif, H., Rebbas, K., Rabah, B., Hammou, M. A. & Maggi, F. (2019). Medicinal plants and their traditional uses in the highland region of Bordj Bou Arreridj (Northeast Algeria). *Journal of Herbal Medicine*, 16, 100262, https://doi.org/https://doi.org/10.1016/j.hermed.2019.100262

Miara, M. D., Teixidor-Toneu, I., Sahnoun, T., Bendif, H. & Ait Hammou, M. (2019). Herbal remedies and traditional knowledge of the Tuareg community in the region of Illizi (Algerian Sahara). *Journal of Arid Environments*, 167, 65–73, https://doi.org/10.1016/J.JARIDENV.2019.04.020

Mohd Subakir, F. N., Zaharudin, N., Mohamed Azman, N. A., & Samat, N. (2022). Thiobarbituric Reactive Substance (TBARS) and sensory evaluation of breast chicken meat from broiler fed with Kappaphycus alvarezii and Sargassum polycystum seaweeds formulated feed. *Food Research*, 6, 107–115, https://doi.org/10.26656/FR.2017.6(S2).022

Mohebodini, H., Jazi, V., Ashayerizadeh, A., Toghyani, M. & Tellez-Isaias, G. (2021). Productive parameters, cecal microflora, nutrient digestibility, antioxidant status, and thigh muscle fatty acid profile in broiler chickens fed with Eucalyptus globulus essential oil. *Poultry Science*, 100 (3), 100922, https://doi.org/https://doi.org/10.1016/j.psj.2020.12.020

Moraes-Lovison, M., Marostegan, L. F. P., Peres, M. S., Menezes, I. F., Ghiraldi, M., Rodrigues, R. A. F., Fernandes, A. M. & Pinho, S. C. (2017). Nanoemulsions encapsulating oregano essential oil: Production, stability, antibacterial activity and incorporation in chicken pâté. *LWT*, 77, 233–240, https://doi.org/10.1016/j.lwt.2016.11.061

Muhialdin, B. J., Kadum, H., Fathallah, S. & Meor Hussin, A. S. (2020). Metabolomics profiling and antibacterial activity of fermented ginger paste extends the shelf life of chicken meat. *LWT*, 132, 109897, https://doi.org/https://doi.org/10.1016/j.lwt.2020.109897

Munekata, P. E. S., Calomeni, A. V, Rodrigues, C. E. C., Fávaro-Trindade, C. S., de Alencar, S. M. & Trindade, M. A. (2015). Peanut skin extract reduces lipid oxidation in cooked chicken patties. *Poultry Science*, https://doi.org/10.3382/ps/pev005

Muthukumar, J., Selvasekaran, P., Lokanadham, M. & Chidambaram, R. (2020). Food and food products associated with food allergy and food intolerance — An overview. In *Food Research International* (Vol. 138). Elsevier Ltd, https://doi.org/10.1016/j.foodres.2020.109780

Najeeb, A. P., Mandal, P. K. & Pal, U. K. (2015). Efficacy of leaves (drumstick, mint and curry leaves) powder as natural preservatives in restructured chicken block. *Journal of Food Science and Technology*, 52 (5), 3129–3133, https://doi.org/10.1007/s13197-014-1316-8

Nandi S. & Guha P. (2024). Development, characterization and application of starch-based film containing polyphenols of piper betle L. waste in chicken meat storage. *Food Chemistry*, 431, 137103, DOI: https://doi.org/10.1016/j.foodchem.2023.137103.

Naveena, B. M., Sen, A. R., Vaithiyanathan, S., Babji, Y. & Kondaiah, N. (2008). Comparative efficacy of pomegranate juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties. *Meat Science*, 80 (4), 1304–1308, https://doi.org/10.1016/j.meatsci.2008.06.005

Nayak, B., Dahmoune, F., Moussi, K., Remini, H., Dairi, S., Aoun, O. & Khodir, M. (2015). Comparison of microwave, ultrasound and accelerated-assisted solvent extraction for recovery of polyphenols from Citrus sinensis peels. *Food Chemistry*, 187, 507–516, https://doi.org/https://doi.org/10.1016/j.foodchem.2015.04.081

Nguyen, M. M. & Karboune, S. (2023). Combinatorial Interactions of Essential Oils Enriched with Individual Polyphenols, Polyphenol Mixes, and Plant Extracts: Multi-Antioxidant Systems. *Antioxidants*, 12 (2), https://doi.org/10.3390/antiox12020486

Noori, S., Zeynali, F. & Almasi, H. (2018). Antimicrobial and antioxidant efficiency of nanoemulsion-based edible coating containing ginger (Zingiber officinale) essential oil and its effect on safety and quality attributes of chicken breast fillets. *Food Control*, 84, 312–320, https://doi.org/10.1016/j.foodcont.2017.08.015

Oliveira, V., Ferreira, F., Cople, M., Labre, T., Augusta, I., Gamallo, O. & Saldanha, T. (2018). Use of Natural Antioxidants in the Inhibition of Cholesterol Oxidation: A Review: Inhibition of cholesterol oxidation…. *Comprehensive Reviews in Food Science and Food Safety*, 17, https://doi.org/10.1111/1541-4337.12386

Oluyemisi Folashade, K., Eghrevba, H. O. & Ahmadu, P. O. (2012). Standardization of herbal medicines — A review. *International Journal of Biodiversity and Conservation*, 4 (3), https://doi.org/10.5897/ijbc11.163

Omotayo, O. P., Omotayo, A. O., Mwanza, M. & Babalola, O. O. (2019). Prevalence of mycotoxins and their consequences on human health. In *Toxicological Research* (Vol. 35, Issue 1, pp. 1–7). Korean Society of Toxicology, https://doi.org/10.5487/TR.2019.35.1.001

Ouali, A., Gagaoua, M., Boudida, Y., Becila, S., Boudjellal, A., Herrera-Mendez, C. H. & Sentandreu, M. A. (2013). Biomarkers of meat tenderness: Present knowledge and perspectives in regards to our current understanding of the mechanisms involved. *Meat Science*, 95 (4), 854–870, https://doi.org/https://doi.org/10.1016/j.meatsci.2013.05.010

Pateiro, M., Gómez-Salazar, J. A., Jaime-Patlán, M., Sosa-Morales, M. E. & Lorenzo, J. M. (2021). Plant extracts obtained with green solvents as natural antioxidants in fresh meat products. In *Antioxidants* (Vol. 10, Issue 2, pp. 1–21). MDPI, https://doi.org/10.3390/antiox10020181

Pferschy-Wenzig, E.-M. & Bauer, R. (2015). The relevance of pharmacognosy in pharmacological research on herbal medicinal products. *Epilepsy & Behavior*, 52, 344–362, https://doi.org/https://doi.org/10.1016/j.yebeh.2015.05.037

Pinto, L., Tapia-Rodríguez, M. R., Baruzzi, F., & Ayala-Zavala, J. F. (2023). Plant Antimicrobials for Food Quality and Safety: Recent Views and Future Challenges. In Foods (Vol. 12, Issue 12). MDPI, https://doi.org/10.3390/foods12122315

Polka, D. & Podsędek, A. (2019). Biotechnology and Food Science Phenolics composition and antioxidant capacity of guelder rose fruit, flower and bark extracts. In *Biotechnol Food Sci* (Vol. 83, Issue 1), http://www.bfs.p.lodz.pl

Qi, J., Du, C., Yao, X., Yang, C., Zhang, Q. & Liu, D. (2022). Enrichment of taste and aroma compounds in braised soup during repeated stewing of chicken meat. *LWT*, 168, 113926, https://doi.org/https://doi.org/10.1016/j.lwt.2022.113926

Qiu, L., Zhang, M., Chitrakar, B., Adhikari, B. & Yang, C. (2022). Effects of nanoemulsion-based chicken bone gelatin-chitosan coatings with cinnamon essential oil and rosemary extract on the storage quality of ready-to-eat chicken patties. *Food Packaging and Shelf Life*, 34, https://doi.org/10.1016/j.fpsl.2022.100933

Radha Krishnan, K., Babuskin, S., Azhagu Saravana Babu, P., Sasikala, M., Sabina, K., Archana, G., Sivarajan, M., & Sukumar, M. (2014). Antimicrobial and antioxidant effects of spice extracts on the shelf life extension of raw chicken meat. *International Journal of Food Microbiology*, 171, 32–40.

Rafińska, K., Wrona, O., Krakowska-Sieprawska, A., Walczak-Skierska, J., Kiełbasa, A., Rafiński, Z., Pomastowski, P., Kolankowski, M. & Buszewski, B. (2022). Enzyme-assisted extraction of plant material — New functional aspects of the process on an example of Medicago sativa L. *Industrial Crops and Products*, 187, 115424, https://doi.org/https://doi.org/10.1016/j.indcrop.2022.115424

Rahim, M. Z., Prinsi, B., Espen, L., Benabdelkader, T., Nabiev, M. & Houali, K. (2022). Comparative analysis of the chemical constituents and in vitro antioxidant activities of different aqueous extracts of the Cistanche phelypaea (L.) Cout. from Algeria. *South African Journal of Botany*, 148, 259–267, https://doi.org/10.1016/j.sajb.2022.04.041

Rani, Z. T., Hugo, A., Hugo, C. J., Vimiso, P. & Muchenje, V. (2017). Effect of post-slaughter handling during distribution on microbiological quality and safety of meat in the formal and informal sectors of South Africa: A review. *South African Journal of Animal Science*, 47 (3), 255–267, https://doi.org/10.4314/sajas.v47i3.2

Rimini, S., Petracci, M., & Smith, D. P. (2014). The use of thyme and orange essential oils blend to improve quality traits of marinated chicken meat. *Poultry Science*, 93 (8), 2096–2102, https://doi.org/10.3382/ps.2013-03601

Rosa, A., Deiana, M., Casu, V., Paccagnini, S., Appendino, G., Ballero, M. & Dessí, M. A. (2002). Antioxidant Activity of Capsinoids. *Journal of Agricultural and Food Chemistry*, 50 (25), 7396–7401, https://doi.org/10.1021/jf020431w

Rout, S., Tambe, S., Deshmukh, R. K., Mali, S., Cruz, J., Srivastav, P. P., Amin, P. D., Gaikwad, K. K., Andrade, E. H. de A. & Oliveira, M. S. de. (2022). Recent trends in the application of essential oils: The next generation of food preservation and food packaging. In *Trends in Food Science and Technology* (Vol. 129, pp. 421–439). Elsevier Ltd, https://doi.org/10.1016/j.tifs.2022.10.012

Sajad, S., Ahmad, I. S., Snober Irshad, I., Qureshi, I. A., Aaliya Fayaz, I., Farukh Mehraj, I., Heena Jalal, I., Corresponding Author, I., Ahmad, S., Irshad, S., Qureshi, A., Fayaz, A., Mehraj, F. & Jalal, H. (2020). Influence of the aqueous extract of dandelion (Taraxacum officinale) powder on the quality of chicken meat loaves. ~ *1579 ~ Journal of Entomology and Zoology Studies*, 8 (4), 1579–1582, http://www.entomoljournal.com

Saleh, E., Morshdy, A. E., El-Manakhly, E., Al-Rashed, S., Hetta, H. F., Jeandet, P., Yahia, R., El-Saber Batiha, G. & Ali, E. (2020). Effects of olive leaf extracts as natural preservative on retailed poultry meat quality. *Foods*, 9 (8), https://doi.org/10.3390/foods9081017

Sallam, K. I., Ishioroshi, M. & Samejima, K. (2004). Antioxidant and antimicrobial effects of garlic in chicken sausage. *LWT*, 37 (8), 849–855, https://doi.org/10.1016/j.lwt.2004.04.001

Sampaio, G. R., Saldanha, T., Soares, R. A. M., & Torres, E. A. F. S. (2012). Effect of natural antioxidant combinations on lipid oxidation in cooked chicken meat during refrigerated storage. *Food Chemistry*, 135 (3), 1383–1390, https://doi.org/10.1016/j.foodchem.2012.05.103

Seidavi, A., Tavakoli, M., Slozhenkina, M., Gorlov, I., Hashem, N. M., Asroosh, F., Taha, A. E., Abd El-Hack, M. E., & Swelum, A. A. (2021). The use of some plant-derived products as effective alternatives to antibiotic growth promoters in organic poultry production: a review. In *Environmental Science and Pollution Research* (Vol. 28, Issue 35, pp. 47856–47868). Springer Science and Business Media Deutschland GmbH, https://doi.org/10.1007/s11356-021-15460-7

Seol K.-H., Joo B.-J., Kim H., Chang O.-K.I., Ham J., Oh M.-H., Park B.-Y. & Lee M. (2013). Effect of Medicinal Plant Extract Incorporated Carrageenan Based Films on Shelf-Life of Chicken Breast Meat. *Korean Journal for Food Science of Animal Resources*, 33, DOI: 10.5851/kosfa.2013.33.1.53.

Seukep, A. J., Kuete, V., Nahar, L., Sarker, S. D. & Guo, M. (2020). Plant-derived secondary metabolites as the main source of efflux pump inhibitors and methods for identification. *Journal of Pharmaceutical Analysis*, 10 (4), 277–290, https://doi.org/https://doi.org/10.1016/j.jpha.2019.11.002

Shah, M. A., Bosco, S. J. D. & Mir, S. A. (2014). Plant extracts as natural antioxidants in meat and meat products. In *Meat Science* (Vol. 98, Issue 1, pp. 21–33). Elsevier BV, https://doi.org/10.1016/j.meatsci.2014.03.020

Sharma, H., Narshimhaji, Ch. V. & Singh, R. (2023). Relative estimation of beta-sitosterol in alcoholic extracts of roots and small branches of oroxylum indicum (L.) Kurz by HPTLC for plant part substitution, medicinal uses and conservation. *Journal of Applied Research on Medicinal and Aromatic Plants*, 35, 100496, https://doi.org/https://doi.org/10.1016/j.jarmap.2023.100496

Sirocchi, V., Caprioli, G., Cecchini, C., Coman, M., Cresci, A., Maggi, F., Papa, F., Ricciutelli, M., Vittori, S. & Sagratini, G. (2013). Biogenic Amines as freshness index of meat wrapped in an innovative active packaging system formulated with essential oils of Rosmarinus officinalis L. *International Journal of Food Science and Nutrition*, 64, https://doi.org/10.3109/09637486.2013.809706

Skochko, O. I., Shevchenko, I. I., Polichuk, G. E. & Paska, M. Z. (2018). The estimation of effects of food crioprotectors on quality indicators of semi-fragrances. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies*, 20 (90), 27–31, https://doi.org/10.32718/nvlvet9006

Steier, G. (2016). Textbox: Cross-Contamination, Genetic Drift, and the Question of GMO Co-existence with Non-GM Crops. In *International Food Law and Policy* (pp. 177–178), https://doi.org/10.1007/978-3-319-07542-6_7

Stojanović-Radić, Z., Pejčić, M., Joković, N., Jokanović, M., Ivić, M., Šojić, B., Škaljac, S., Stojanović, P. & Mihajilov-Krstev, T. (2018). Inhibition of Salmonella Enteritidis growth and storage stability in chicken meat treated with basil and rosemary essential o ils alone or in combination. *Food Control*, 90, 332–343, https://doi.org/10.1016/j.foodcont.2018.03.013

Surekha, M. & Reddy, S. M. (2014). Preservatives | Classification and Properties. In C. A. Batt & M. Lou Tortorello (Eds.), *Encyclopedia of Food Microbiology (Second Edition)* (pp. 69–75). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-384730-0.00257-3

Tajik, H., Farhangfar, A., Moradi, M. & Razavi Rohani, S. M. (2014). Effectiveness of Clove Essential Oil and Grape Seed Extract Combination on Microbial and Lipid Oxidation Characteristics of Raw Buffalo Patty During Storage at Abuse Refrigeration Temperature. *Journal of Food Processing and Preservation*, 38, https://doi.org/10.1111/j.1745-4549.2012.00736.x

Tang, S. Z., Kerry, J. P., Sheehan, D. & Buckley, D. J. (2002). *Antioxidative mechanisms of tea catechins in chicken meat systems*. www.elsevier.com/locate/foodchem

Tengilimoglu-Metin, M. M., Hamzalioglu, A., Gokmen, V., & Kizil, M. (2017). Inhibitory effect of hawthorn extract on heterocyclic aromatic amine formation in beef and chicken breast meat. *Food Research International*, 99, 586–595, https://doi.org/10.1016/j.foodres.2017.06.044

Terlouw, C. E. M., Picard, B., Deiss, V., Berri, C., Hocquette, J. F., Lebret, B., Lefèvre, F., Hamill, R. & Gagaoua, M. (2021). Understanding the determination of meat quality using biochemical characteristics of the muscle: Stress at slaughter and other missing keys. *Foods* 10 (1). MDPI AG, https://doi.org/10.3390/foods10010084

Thakur, N., Mendiratta, S., Chauhan, G., Soni, A. & Agrawal, R. (2019). Antioxidant and Antimicrobial Effect of Oregano Essential Oil on Shelf-Life of Chicken Patties. *International Journal of Current Microbiology and Applied Sciences*, 8, 3076–3087, https://doi.org/10.20546/ijcmas.2019.802.360

Thielmann, J., Muranyi, P. & Kazman, P. (2019). Screening essential oils for their antimicrobial activities against the foodborne pathogenic bacteria Escherichia coli and Staphylococcus aureus. *Heliyon*, 5 (6), https://doi.org/10.1016/j.heliyon.2019.e01860

Thomas, J., Patel, A., Das Sivadasan, S., Sreevallabhan, S., Illathu Madhavamenon, K. & Mohanan, R. (2022). Clove bud (Syzygium aromaticum L.) polyphenol helps to mitigate metabolic syndrome by establishing intracellular redox homeostasis and glucose metabolism: A randomized, double-blinded, active-controlled comparative study. *Journal of Functional Foods*, 98, https://doi.org/10.1016/j.jff.2022.105273

Thompson, T., Busetti, A. & Gilmore, B. (2023). Quorum Sensing in Halorubrum saccharovorum Facilitates Cross-Domain Signaling between Archaea and Bacteria. *Microorganisms*, 11, 1271, https://doi.org/10.3390/microorganisms11051271

Tian, H., Li, F., Qin, L., Yu, H. & Ma, X. (2014). Discrimination of Chicken Seasonings and Beef Seasonings Using Electronic Nose and Sensory Evaluation. *Journal of Food Science*, 79, https://doi.org/10.1111/1750-3841.12675

Tobiszewski, M. & Namieśnik, J. (2017). Greener organic solvents in analytical chemistry. *Current Opinion in Green and Sustainable Chemistry*, 5, 1–4, https://doi.org/https://doi.org/10.1016/j.cogsc.2017.03.002

Tresserra-Rimbau, A., Lamuela-Raventos, R. M. & Moreno, J. J. (2018). Polyphenols, food and pharma. Current knowledge and directions for future research. In *Biochemical Pharmacology* (Vol. 156, pp. 186–195). Elsevier Inc, https://doi.org/10.1016/j.bcp.2018.07.050

Twaij, B. M. & Hasan, M. N. (2022). Bioactive Secondary Metabolites from Plant Sources: Types, Synthesis, and Their Therapeutic Uses. *International Journal of Plant Biology*, 13 (1), 4–14, https://doi.org/10.3390/ijpb13010003

Vara, S., Karnena, M. K. & Dwarapureddi, B. K. (2019). 6 — Natural Preservatives for Nonalcoholic Beverages. In A. M. Grumezescu & A. M. Holban (Eds.), *Preservatives* *and Preservation Approaches in Beverages* (pp. 179–201). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-816685-7.00006-9

Vauzour, D., Rodriguez-Mateos, A., Corona, G., Oruna-Concha, M. J. & Spencer, J. P. E. (2010). Polyphenols and human health: Prevention of disease and mechanisms of action. *Nutrients* 2 (11), pp. 1106–1131, MDPI AG, https://doi.org/10.3390/nu2111106

Vinci, G., Maddaloni, L., Prencipe, S. A., & Bernardo, A. (2022). Integrated Study for the Shelf-life Evaluation in Food: Use of Spices, Herbs, and Bio-packaging. In Emerging Challenges in Agriculture and Food Science Vol. 7 (pp. 40–50). Book Publisher International (a part of SCIENCEDOMAIN International), https://doi.org/10.9734/bpi/ecafs/v7/3676A

Vranić, D., Milićević, D., Korićanac, V., Trbović, D., Babić, J., Petrović, Z. & Parunović, N. (2014). Cholesterol and total lipid content in raw and heat processed commercially produced meat from two farms. *Meat Technology*, 55 (2), 130–141, https://www.journalmeattechnology.com/index.php/meat_technology/article/view/195/144

Wang, J., Ren, B., Bak, K. H., Soladoye, O. P., Gagaoua, M., Ruiz-Carrascal, J., Huang, Y., Zhao, Z., Zhao, Y., Fu, Y. & Wu, W. (2023). Preservative effects of composite biopreservatives on goat meat during chilled storage: Insights into meat quality, high-throughput sequencing and molecular docking. *LWT*, 184, 115033, https://doi.org/https://doi.org/10.1016/j.lwt.2023.115033

Wang, W., Zhao, D., Xiang, Q., Li, K., Wang, B., & Bai, Y. (2021). Effect of cinnamon essential oil nanoemulsions on microbiological safety and quality properties of chicken breast fillets during refrigerated storage. *LWT*, 152, https://doi.org/10.1016/j.lwt.2021.112376

Weil, B. & Veraitch, F. (2014). *Bioprocessing Challenges Associated with the Purification of Cellular Therapies* (pp. 129–156), https://doi.org/10.1007/978-94-007-7196-3_6

Weng, Z., Zeng, F., Wang, M., Guo, S., Tang, Z., Itagaki, K., Lin, Y., Shen, X., Cao, Y., Duan, J. & Wang, F. (2023). Antimicrobial activities of lavandulylated flavonoids in Sophora flavences against methicillin-resistant Staphylococcus aureus via membrane disruption. *Journal of Advanced Research*, https://doi.org/https://doi.org/10.1016/j.jare.2023.04.017

Wideman, N., O'Bryan, C. A. & Crandall, P. G. (2016). Factors affecting poultry meat colour and consumer preferences — A review. *World's Poultry Science Journal*, 72 (2), 353–366, https://doi.org/DOI: 10.1017/S0043933916000015

Woroń, J. & Siwek, M. (2018). Unwanted effects of psychotropic drug interactions with medicinal products and diet supplements containing plant extracts. *Psychiatria Polska*, 52 (6), 983–996, https://doi.org/10.12740/PP/OnlineFirst/80998

Wu, H., Bak, K. H., Goran, G. V. & Tatiyaborworntham, N. (2022). Inhibitory mechanisms of polyphenols on heme protein-mediated lipid oxidation in muscle food: New insights and advances. In *Critical Reviews in Food Science and Nutrition*. Taylor and Francis Ltd, https://doi.org/10.1080/10408398.2022.2146654

Wu, Q. & Zhou, J. (2021). Chapter Two — The application of polyphenols in food preservation. In D. Granato (Ed.), *Advances in Food and Nutrition Research* (Vol. 98, pp. 35–99). Academic Press, https://doi.org/https://doi.org/10.1016/bs.afnr.2021.02.005

Xie, Y., Geng, Y., Yao, J., Ji, J., Chen, F., Xiao, J., Hu, X. & Ma, L. (2023). N-nitrosamines in processed meats: Exposure, formation and mitigation strategies. *Journal of Agriculture and Food Research*, 13, https://doi.org/10.1016/j.jafr.2023.100645

Yan, Z., Zhong, Y., Duan, Y., Chen, Q. & Li, F. (2020). Antioxidant mechanism of tea polyphenols and its impact on health benefits. In *Animal Nutrition* (Vol. 6, Issue 2, pp. 115–123). KeAi Communications Co, https://doi.org/10.1016/j.aninu.2020.01.001

Youssef, E. A., Saad, S. M., Hassan, M. A. & Ibrahim, H. M. (2021). Assessment of the effects of selected plant extracts on quality indices and shelf life of raw chilled chicken meat. *Benha Veterinary Medical Journal* (Vol. 40).

Yu, H. H., Chin, Y. W. & Paik, H. D. (2021). Application of natural preservatives for meat and meat products against food-borne pathogens and spoilage bacteria: A review. In *Foods* (Vol. 10, Issue 10). MDPI, https://doi.org/10.3390/foods10102418

Zhang, D., Ivane, N. M. A., Haruna, S. A., Zekrumah, M., Elysé, F. K. R., Tahir, H. E., Wang, G., Wang, C. & Zou, X. (2022). Recent trends in the micro-encapsulation of plant-derived compounds and their specific application in meat as antioxidants and antimicrobials. In *Meat Science* (Vol. 191). Elsevier Ltd, https://doi.org/10.1016/j.meatsci.2022.108842

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, https://doi.org/10.1016/j.fshw.2015.11.003

Zhang, L. & Piao, X. (2023). Use of aromatic plant-derived essential oils in meat and derived products: Phytochemical compositions, functional properties, and encapsulation. In *Food Bioscience* (Vol. 53). Elsevier Ltd, https://doi.org/10.1016/j.fbio.2023.102520

Zheng, K., Li, B., Liu, Y., Wu, D., Bai, Y. & Xiang, Q. (2023). Effect of chitosan coating incorporated with oregano essential oil on microbial inactivation and quality properties of refrigerated chicken breasts. *LWT*, 176, https://doi.org/10.1016/j.lwt.2023.114547

Zhou, X., Zong, X., Zhang, M., Ge, Q., Qi, J., Liang, J., Xu, X. & Xiong, G. (2021). Effect of konjac glucomannan/carrageenan-based edible emulsion coatings with camellia oil on quality and shelf-life of chicken meat. *International Journal of Biological Macromolecules*, 183, 331–339, https://doi.org/10.1016/j.ijbiomac.2021.04.165

Zhu, Y., Li, X., Da, C., Liang, P., Jin, S., & Tang, C. (2022). Effects of Cyclocarya paliurus (Batal.) Extracts on Oxidative Stability and Sensory Quality in Meat Products (Frankfurters). *Foods*, 11 (22), https://doi.org/10.3390/foods11223721