Essential Oils and Plant Extracts as Preservatives and Natural Antioxidants
Applied to Meat and Meat Products: A Review

Running title: Natural Products Applied to Meat Products

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SUMMARY

The meat and meat products industry has evolved according to the needs of the market. Consumers are increasingly seeking quality in food. Thus, the concern regarding the excessive use of additives such as preservatives and antioxidants has driven research for natural, healthy and safe substitutes. Essential oils and plant extracts have been shown to be a good option for resolving this demand. The fact that they are completely natural, linked to the biological activity of their constituents, and acting mainly by preventing oxidation and the proliferation of microorganisms has aroused the interest of the industry and consumers. This review will present studies published in the last five years regarding the potential of essential oils and plant extracts to act as preservatives and antioxidants in meat and meat products. The forms of application, innovations in the area, alternatives to the incorporation of essential oils and extracts in meat products, effects caused in food, and limitations of applications will be detailed and discussed.

Keywords: natural compounds; antimicrobial activity; antioxidant activity

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INTRODUCTION

Meat can be defined as animal tissue that is suitable for human consumption. Like meat, its derivatives are complex, highly perishable foods and have in their composition, in addition to proteins, saturated and unsaturated lipids, carbohydrates, vitamins and pigments that can undergo oxidation reactions and microbial deterioration. Thus, the shelf life of meat is influenced by several factors, such as storage temperature, enzyme action, oxygen, humidity, light and microorganisms. The influence of these factors is worrisome because they directly interfere with the quality of food, both nutritionally and in sensory aspects. They can cause changes in attributes such as texture, color, odor, flavor and aroma (1,2).

Oxidation is a process that frequently occurs in meat during storage. The oxidation of lipids, proteins and pigments directly interferes with the sensory and nutritional quality of the product. In addition, toxic compounds can be produced (3,1). Oxidation is a factor that must be controlled in meat. However, the proliferation of microorganisms is a factor that deserves even more attention because of the harm they can cause to consumers.

The contaminating and spoilage microorganisms in meat are mostly pathogenic bacteria Campylobacter spp., Listeria monocytogenes, Staphylococcus aureus, Salmonella enterica and Escherichia coli, which are responsible for foodborne outbreaks. The bacterial genera that deserve attention are Acinetobacter, Alteromonas, Aeromonas, Brochothrix, Flavobacterium, Leuconostoc, Pseudomonas, Moraxella, Lactic acid bacteria and those belonging to the Enterobacteriaceae family (4,5).

The use of food additives, such as preservatives and antioxidants, has been of global concern in recent years. One of the foods that generate greater concern regarding the use of additives is meat and its derived products. Coming from cattle, swine or poultry, meat and meat products are highly perishable, susceptible to the action of various microorganisms and lipid oxidation. Therefore, methods to maintain quality and increase their shelf life are required, one of the methods being the addition of antioxidants and preservatives.

The food industry has constantly sought ways to minimize the loss of quality in meat and its derivatives and increase its shelf life. Conservation methods such as low temperature, specific packaging and adequate storage are frequently used. In addition, the use of additives that act as preservatives and antioxidants is often essential to ensure the quality of meat and its derivatives. However, the use of synthetic additives can be harmful to health, and this fact is increasingly noticeable to consumers, who are searching for healthy foods that are more natural, and they have a
preference for natural compounds (6). According to Lin and Wu (6), the fact that plants are the main natural source of antioxidants and, in general, do not pose risks to food safety, makes the use of plant derivatives as antioxidants valuable. Economic growth and the emergence of new technologies have also increased the demand for natural products. Thus, the application of compounds, such as essential oils and plant extracts, that act as natural preservatives emerge as an interesting strategy to reduce or replace the use of traditional synthetic additives if they are equally efficient (6,7).

This review will address some alternatives researched in the last five years for the application of essential oils and plant extracts in meat and meat products with the aim of preserving and replacing, in whole or in part, synthetic preservatives and antioxidants generally applied to these foods. In addition, the mechanisms of antioxidant and antimicrobial action of the natural products under study will be briefly discussed.

ESSENTIAL OILS AND PLANT EXTRACTS

Essential oils are volatile organic compounds synthesized by plants in response to physiological stress, ecological factors and pathogen attack, as well as acting to attract pollinators to facilitate reproduction (8). They can be defined as “the product obtained from a natural raw material of vegetable origin by steam distillation, from the epicarp of citrus fruits by mechanical processes or by dry distillation, after separation of the aqueous phase, if any, by physical processes.” ISO 9235:2013 also emphasizes that steam distillation can be performed with the addition of water to the distillate, this process being called hydrodistillation (9).

The main characteristics presented by essential oils are their complex compositions of low molecular weight molecules with different chemical structures that include monoterpenes, sesquiterpenes, alcohols, aldehydes, esters, ethers, ketones, various phenylpropanoid derivatives and various volatile organic compounds. In addition, they are liquid at room temperature and hydrophobic so they have low water solubility (10,11).

Vegetable extracts, unlike essential oils, are preparations obtained from the extraction of the active constituents of vegetables and must contain “sapid, aromatic, volatile and fixed principles corresponding to the respective natural product”. The extraction of active ingredients can occur using different solvents such as methanol, ethyl acetate, hexane, ethanol, or acetone, and the material used in the extraction can be previously treated by means of enzymatic inactivation, milling or degreasing. After extraction, undesirable compounds can also be eliminated by purifying the extract (12,13).
Essential oils and plant extracts, in addition to being natural products extracted from plants, are mostly considered to be GRAS (Generally Recognized As Safe), which allows their use in food products without posing risks to consumers. In addition, different biological activities can be attributed to them, including antioxidant and antimicrobial activity, depending on their compositions. Phenolic compounds, alcohols, aldehydes, phenylpropanoids, terpenes and ketones are the principal constituents responsible for the antioxidant activity of essential oils. They protect against pro-oxidants naturally present in meat, such as free iron ions (1). In terms of antimicrobial activity, the constituents that stand out are those containing aromatic oxygen compounds with carbonyl groups (aldehydes and ketones), phenols, ethers or acids, followed by oxygenated aliphatic terpenes (14).

Plant extracts also contain phytochemicals of interest. Those that stand out, such as phenolic compounds, have antioxidant and antimicrobial activities. In particular, there are the tannins and flavonoids that can be subclassified into flavones, flavanones, flavonols, flavanonols, isoflavones, catechins and anthocyanidins (15,16).

MECHANISM OF ANTIMICROBIAL ACTION OF ESSENTIAL OILS AND PLANT EXTRACTS

Psychrotrophic bacteria as Psychrotrophic Pseudomonas, Psychrotrophic lactic acid bacteria, psychrotrophic Enterobacteriaceae, psychrotrophic Clostridium spp. are one of the principal spoilage groups in freshly stored and refrigerated meats because they have the ability to develop at temperatures below 7 °C. The activity of essential oils and plant extracts against microorganisms is directly related to their constituents. However, it is worth noting that the combination of constituents can act synergistically in the antimicrobial mechanism (17,18,19).

The principal mechanism of action of both essential oils and plant extracts involves the interaction with the cell membrane of microorganisms (Fig. 1). These natural compounds can act by increasing membrane permeability, inhibiting the absorption of substrates that are important for development, and interfering with the cellular metabolism (20,21).

Studies report that Gram-positive bacteria are more susceptible to the action of the constituents. This observation can be explained by the involvement of the lipopolysaccharide layer present in the cell wall of Gram-negative bacteria. This layer limits the diffusion of hydrophobic compounds, such as essential oils (22).

Thus, the mechanism of action of the essential oils involves the interaction of their constituents with the cell membranes of microorganisms, which are composed of lipids. The cell membrane, when interacting with constituents, can be damaged, leading to an increase in membrane permeability and
impairment of functions in the cell such as nutrient uptake, electron transport, nucleic acid synthesis, enzyme activity and can even cause death. In addition, the constituent molecules of essential oils can cross the membrane and reach the cytoplasm, where they can react with other cellular components (4,23).

Fig. 1

MECHANISM OF ANTIOXIDANT ACTION OF ESSENTIAL OILS AND PLANT EXTRACTS

The oxidation of lipids present in meat leads to the formation of hydroperoxides, which in turn generate degradation products in meat and compounds such as volatile and undesirable aldehydes, ketones, acids and alcohols. Protein oxidation causes changes in proteins and amino acids. Thus, the level of digestibility, solubility and bioavailability can be reduced. Pigments, such as myoglobin, which is one of the main pigments responsible for the color of the product, form brown compounds when oxidized and thus affect the appearance of meats (24,25).

The phenolic compounds present in plant extracts are considered to be the main group responsible for the antioxidant activity of the extracts. In essential oils, phenylpropanoids and terpenoids with phenolic characteristics also have antioxidant activities. These compounds can act in the stabilization of free radicals because their structures bear a hydroxyl group (-OH) on a benzene ring. Thus, they can act by transferring the H atom from the OH group to the free radical, as reducing agents and singlet oxygen inhibitors, as shown in Fig. 2 (21,26,27).

Fig. 2

APPLICATIONS OF ESSENTIAL OILS AND PLANT EXTRACTS AS PRESERVATIVES AND ANTIOXIDANTS IN FRESH MEAT AND MEAT PRODUCTS

The proliferation of microorganisms can cause deterioration and contamination of the product, making its commercialization and consumption unfeasible. Food industries, in general, add antioxidants and preservatives to meat products to preserve their microbiological, physical-chemical and sensory characteristics. Thus, the application of essential oils and plant extracts to meat products has been shown to be a natural and efficient alternative to preserve these products, preventing the proliferation and action of microorganisms.

The application of natural compounds such as essential oils and plant extracts in meat products basically boils down to the direct application to the meat product, whether diluted or not, and application through nanoemulsions, nanoparticles and active and intelligent packaging, such as films
and coatings. In all the forms of application, a combination with other conservation methods, such as refrigeration, freezing and appropriate packaging, is necessary.

**Application of essential oils and plant extracts directly on meat and meat products: preservative and antioxidant action**

Some of the main studies on the direct application of essential oils and plant extracts to meat and meat products are presented in Table 1 and Table 2, respectively. Danilovic et al. (22) evaluated the application of essential oils and sage extract to pork to control *E. coli*. Pork pieces were treated separately with essential oil and extract. The results showed that, after 14 days, a significant inhibition of *E. coli* growth at all concentrations was observed in the treatments involving the addition of the essential oil. The samples treated with sage extract had a smaller effect against the microorganism evaluated than the treatment with the essential oil, but the proliferation of the bacteria decreased to a concentration of 1.0 µL/g. However, regardless of the treatment used, the number of *E. coli* did not increase in the first eight days of storage, and treatments with essential oil and extract were considered by the authors to be effective methods of controlling this bacterium.

The effect of other essential oils on meat products was also presented as relevant studies in the data collection achieved for the elaboration of this review. Ozaki et al. (29), seeking to reduce nitrite in “salaminho”, a product made with pork and beef and fermented during processing, used the essential oil from oregano (100 mg/kg) together with radish powder (0.5 and 1 %). The salami were stored for 30 and 60 days at 4 and 20 °C, and, despite the sensory acceptance and known activity of oregano essential oil, this oil did not inhibit lipid oxidation and did not show antimicrobial activity at the concentration employed. This observation was probably due to the low concentration added and a possible decrease in the concentration of bioactive compounds in the commercial oil (29). This study is a good example of the impasse between an effective concentration for antioxidant and antimicrobial action and the sensory acceptance of consumers. This fact is one of the reasons why the application of natural compounds through coatings, films and encapsulation is a good option. On the other hand, Fernandes et al. (35) observed antioxidant activity when he applied oregano extract directly to lamb hamburger as a possible substitute for the synthetic antioxidant erythorbate and stored it for 120 days at -18 °C. In addition, the treated hamburgers did not differ from those produced with a synthetic antioxidant in terms of sensory acceptance.

Harbin sausage, a dry fermented sausage produced in Harbin (China), was evaluated by Sun et al. (37) after adding cinnamon, clove and anise extract. The application of the extracts reduced the
accumulation of biogenic amines, mainly in the treatment containing cinnamon extract, which inhibited the formation of six of the amines analyzed. The inhibitory effect of the extracts might be related to the inhibition of enterobacteriaceae that can increase the production of biogenic amines such as tyramine, putrescine, cadaverine and histamine. The antimicrobial effect of the extracts is probably due to the synergism of their constituents. In the cinnamon extract, which proved to be the most efficient, the presence of eucalyptol and trans-cinnamaldehyde, compounds considered to be antimicrobial, might have cooperated for this effect. Anise extract contains antimicrobial constituents such as carvacrol, linalool, terpineol and eugenol, the latter also being present in clove extract. The presence of polyphenols in the spice extracts also contributed to the antioxidant activity observed, which was higher in the anise extract. A major concern when adding extracts to foods is the alteration of sensory characteristics. In this study, in addition to the improved microbiological characteristics in the presence of the spice extracts, the color and attributes such as flavor, odor, acidity and acceptance received better scores than the control samples.

The use of natural products to replace, even partially, the nitrite preservative has been widely studied. This additive can favor the formation of N-nitrosamines when it reacts with the secondary amines present in the meat. These N-nitrosamines can lead to gastrointestinal cancer (42). Thus, the reduction of the use of nitrite in meat products is a factor of interest to researchers, industry and consumers, and the replacement of this preservative by natural compounds was demonstrated to be a good alternative.

Pinelli et al. (28) evaluated the partial replacement of nitrite by emulsions and nanoemulsions of the essential oils from oregano, lemon, cinnamon, cardamom and pepper in mortadella. Additive or synergistic actions between the components of these oils can be observed when they are mixed. The biological activity of interest increases because of this synergism, which permits the application in lower concentrations with smaller sensory alterations. Although no significant difference in the mean number of Clostridium sporogenes spores was observed for the treatments and the control, the number of C. sporogenes cells was lower than that of the control. Nitrite (75 ppm) was added to the control and the other treatments, with emphasis on nanoemulsion treatments. Thus, treatments with an emulsion or nanoemulsion can be alternatives for the control of this microorganism in products such as mortadella because they were more efficient than nitrite itself. In addition to the microbial control, the treatments influenced the residual nitrite content and the thiobarbituric acid reactive substances (TBARS) index. The residual nitrite content is expected to decrease during the storage of products made with cured meat, and this decrease has indeed occurred. However, the final concentration of residual nitrite in mortadella treated with nanoemulsions was significantly higher than
in the control, with values greater than 45 mg/Kg. It is likely that there were interactions between the oils and nitrite, which increased the antimicrobial activity of these treatments. Regarding the TBARS analysis, the lowest values were observed for treatments with emulsions or nanoemulsions. The presence of constituents that have antioxidant characteristics, such as the phenolic compounds present in the oils, leads to known and scientifically proven antioxidant activities. The emulsions and nanoemulsions have been shown to be a good alternative for reducing nitrite in bologna, but the concentrations used must still be evaluated to reduce the sensory interference that was still unsatisfactory.

Yuan and Yuk (36) applied Syzygium antisepticum extract directly to cooked chicken in an attempt to inhibit the growth of S. aureus. The highest concentration used, 32 mg/mL, inhibited the growth of the microorganism, but the color of the meat was altered, a fact that would influence the consumer acceptance. The application of plant extracts and essential oils directly to food products, as already mentioned, can interfere with consumer acceptance because of the changes they cause in the food, such as color, texture and aroma. For this reason, many researchers opt for application through nanoparticles, nanoemulsions, edible coatings or films.

Table 1

| Table 1 | Table 2 |

Incorporation of essential oils and plant extracts in active packaging applied to meat and meat products: preservative and antioxidant action

The application of essential oils and plant extracts to meats through packaging has been the main focus of many researchers today because it allows the incorporation of active compounds such as antioxidants and antimicrobials and reduces the likelihood of unpleasant sensory changes for the consumer (43). The principal research on the application of essential oils and plant extracts as antioxidants and antimicrobial preservatives incorporated into active packaging and used in meat and meat products is presented in Table 3 and Table 4. Mehdizadeh et al. (47) evaluated the conservation of beef packaged with cornstarch and chitosan-based films containing the essential oil from Thymus kotschyanus and pomegranate peel extract (Punica granatum). A higher antioxidant and antimicrobial activity was observed for the films with combined essential oils and extract. The film containing oil (2 %) and extract (1 %) inhibited the growth of Listeria monocytogenes for 12 days. The effect of the films on the other microorganisms evaluated was also more significant when the oil and the extract were present together. This antimicrobial activity might be related to the principal constituents of the
oil, thymol and carvacrol, and to the interactions of phenolic compounds in the extract with sulfhydryl groups of proteins found in bacterial structures.

Langrooti et al. (55) also evaluated the application of a combination of essential oils and extracts to beef. The results of the application of chitosan-based coatings with the 1% essential oil from *Zataria multiflora* and *Rhus coriaria* extract (2 and 4%) showed that both the extract and the essential oil contributed to the antioxidant activity of the coatings, yielding significantly lower TBARS and peroxide values. The microbial activity was lowest at the highest concentration of extract, and the microbiological quality of all the samples was maintained for 20 days. On the other hand, the quality of the control samples was lost after the fifth day of storage. Therefore, an additive or synergistic effect against the microorganisms evaluated was observed for the combination of the extract with the essential oil.

The ground beef product that undergoes minimal processing can be used for other products such as hamburgers and meatballs. This product was evaluated in various studies that applied the oils and extracts to determine the antioxidant and preservative action of these natural compounds. Almasi et al. (44) developed films based on sodium alginate containing the essential oil from *Thymus vulgaris* to determine the antimicrobial action in ground beef. These authors applied the oil at concentrations of 0.05% and 0.04%, respectively, using two different techniques, microemulsion and nanoemulsion, and they evaluated the antimicrobial activity of ground beef in contact with the film and under refrigeration. A significant antimicrobial activity against all the microorganisms tested was observed with the films made by the microemulsion technique, with emphasis on the number of total mesophiles for which a decrease of 2 logarithmic cycles (100 times) relative to the control was found after eight days of storage. This activity is explained by the greater availability of the essential oil that comes into contact with the meat product when it is present in a microemulsion. In addition, the particles diffuse through the films more easily, which makes the oils more readily available to interfere with the cellular activities of microorganisms. The surfactant micelles formed in the films can fuse with the phospholipid bilayers that make up the cell membrane to increase the interaction with bacterial cells. This interaction thereby increases the antimicrobial activity, which can lead to cell death.

Work by Akcan, Estévez and Serdaroglu (58) showed that interesting results were also obtained with meat products made from ground beef, such as meatballs and hamburgers. Films based on isolated whey proteins containing extracts of *Laurus nobilis* or *Salvia officinalis* were applied to cooked meatballs. Antioxidant activity throughout storage was observed in the presence of the films, but research to improve the sensory acceptability of the product is necessary. Subsequently, Amiri et al. (46) investigated the application of cornstarch-based films made by a nanoemulsion containing
essential oils from *Zataria multiflora* and applied to hamburger steaks. The increase in pH during storage was lower with the films containing essential oils, and the oxidation of protein and lipid was also lower, especially with nanoemulsions.

The oxidative stability increased with the use of smaller nanoemulsion droplets. The product of this study was sensorially well accepted, but there was a decrease in acceptability during the days of storage, whereas the control was unacceptable from the tenth day onwards.

Good results were also obtained when the red cabbage extract was incorporated into films based on starch and whey and applied to ground beef. Sanches *et al.* (57) observed that the films acted as antioxidants, especially at a concentration of 64.15 %, which was sufficient to stabilize oxymyoglobin (57). This bright red pigment is a derivative of myoglobin, one of the main pigments responsible for meat color (2). The antioxidant activity of this film was studied by Sanches *et al.* (57), and they attributed the high concentration of anthocyanins present in the extract as being responsible for this activity. In addition to helping to preserve the characteristics of the meat, the film prepared by Sanches *et al.* (57) possessed the ability to monitor the quality of the product through the color change of the film as the pH changed, and it was thus characterized as a smart packaging. For the authors, the change in the color of the film occurred as a result of the color change of the anthocyanins present. Anthocyanins have a red or purple color (due to the flavylium cation) at low pH, but when submitted to a medium in which the pH is high, they acquire a blue color (formation of quinoidal bases). If the pH continues to increase, the sample becomes colorless (formation of chalcones). High pH values in meat are indicative of microbial spoilage and protein degradation. Therefore, this type of packaging can indicate when the meat is unfit for consumption.

Smart packaging has also been designed for application to lamb meat. The film obtained from chitosan and methylcellulose nanofibers was incorporated with anthocyanin extract from saffron leaves. The extract was applied to meat that was stored for three days at 25 °C. The anthocyanins present in the extract were responsible for changing the color of the film by altering the pH of the meat, which indicated the presence of deterioration. In addition to the indication of quality, the films indicated that antimicrobial and antioxidant activity existed, but these biological activities were not evaluated in the meat (20).

Lamb meat was also evaluated using films embedded with the essential oil from *Rosmarinus officinalis* and coatings embedded with the essential oil from *Satureja khuzestanica*. The films with rosemary essential oil (2 %) were made from whey proteins and possessed antioxidant and
antimicrobial activities. The addition of rosemary oil was efficient to the point of extending the shelf life of the product from about six days to 12 to 15 days (45).

The coatings studied by Alizadeh-Sani, Mohammadianb and Mcclement (45) were made with chitosan and savory essential oil (1 %) and possessed sufficient antioxidant and antimicrobial activities to exceed the recommended microbiological limit (7 Log CFU/g) only after 20 days in the treated samples, whereas the control exceeded this limit after nine days of storage. Previously, Pabast et al. (56) studied the application of chitosan-based coatings and concluded that, even without the addition of essential oils, these coatings were able to reduce the pH and act as antimicrobial agents.

The projections of world consumption and production of chicken that is classified as white meat has increased in recent years (49). Several studies on the application of natural compounds in chickens have been performed. Hosseini et al. (17) studied the effect of adding the essential oils from Aloysia citriodora and Syzygium aromaticum to chicken breasts in the form of coatings. Sodium alginate-based coatings were made with each oil and the combination of the oils. Antioxidant and antimicrobial activities were observed for the oils, and the shelf life of the product increased. The use of a modified atmosphere increased the antibacterial effect, and the best effect was observed in the application of the coating containing two oils at 0.5 %. No significant difference between treatments was observed in the sensory analysis. Good results were also observed with other essential oils, such as those of Cuminum cyminum (50); Nigella sativa (51) and Ziziphora persica (52), that were applied to chicken meat through coatings and films and preserved the meat stored at 4 °C for 9, 5 and 12 days, respectively.

Satisfactory results were obtained with the essential oil from Rosmarinus officinalis when it was incorporated into coatings and applied to chicken breasts. Because Rosmarinus officinalis (rosemary) is a condiment commonly used in meat products in its natural form, consumers tend to recognize the odor and flavor of this plant and do not reject it in coated meat. Thus, the sensory evaluation of the product does not tend to have negative results. Films made from chitosan with rosemary oils were applied to chicken meat, and antioxidant and antimicrobial activities were observed with the coating (63). The total counts of mesophilic aerobic bacteria were lower in the samples treated with the active films. For the authors, the antimicrobial activity of the films is related to chitosan, and the presence of phenolic compounds derived from rosemary essential oil increased the shelf life of the product. The control sample from the third day onwards was rejected. Thus, this study emerged as a new way to complement the necessary daily consumption of phenolic compounds (63).
Oregano is also a condiment widely used in food preparation. In addition to presenting biological activities of interest, it is able to improve the quality when applied to meat, mainly because of the action of its principal compounds, thymol and carvacrol, which are efficient inhibitors of bacterial growth. Xiong et al. (62) applied oregano essential oil incorporated into pectin-based coatings containing a resveratrol nanoemulsion to pork. The meat was stored for 20 days at 4 °C, whereas the total bacterial count in the control sample was considered microbiologically unacceptable from day 15 onwards, exceeding 7 Log CFU/g. The treated samples remained below the limit during the 20 days of storage. Furthermore, lipid oxidation was lower with the treatments, whereas the limit of 0.5 mg MDA/Kg was exceeded in the control on the fifth day. The authors concluded that the essential oil from oregano and resveratrol can scavenge free radicals and stop oxidation chain reactions, facts that explain the reported antioxidant activity.

The antioxidant activity in pork was reported by Song et al. (68) who observed lower TBARS values for the treated meats during storage than for the control when films containing green tea extract were applied. It was also observed that, during storage, the changes in the TBARS values were insignificant in the extract-treated samples.

**Table 3**

**Table 4**

LIMITATIONS OF THE APPLICATION OF ESSENTIAL OILS AND PLANT EXTRACTS IN MEAT AND MEAT PRODUCTS

The biological activity of essential oils and plant extracts is increasingly known among researchers, consumers and industries. The existing demand for healthy products can be met using these natural compounds of low-toxicity (4).

The application of extracts and essential oils to meat and meat products as antioxidant and antimicrobial agents yields excellent results, as was presented in the previous topics. However, the application of these natural compounds to food still faces some technological challenges. According to Silva et al. (4), the complexity of the composition of meat-based foods, such as levels of proteins, lipids, moisture, among others, leads to the interaction of natural compounds with other components of the food, and, thus, they are less readily available to act on microorganisms. Other characteristics, such as water activity and pH, can also influence the performance of natural compounds. Thus, food applications can require concentrations up to 100 times greater than those used in in vitro experiments.
The first point to observe for the application of a compound in food is the food safety that will be offered to consumers. Despite being completely natural, some essential oils and plant extracts can be unsuitable for consumption in certain concentrations. Another important point to be observed is the form of application of the compounds. Despite the biological properties already described, the fact that they present a striking characteristic aroma and flavor makes their application difficult, especially when it comes to food. To facilitate this application, the incorporation into edible, biodegradable coatings and films and made with biopolymers are an alternative for the preservation of food. Thus, it is possible to obtain a material with the activity of interest while improving the value of the food (43,69).

The direct use of natural compounds in meat and meat products, as mentioned, can completely change the sensory characteristics of the product, and it might not be very acceptable to consumers, fact that limits its application (70). Danilovic et al. (22) emphasized the fact that the oils and extracts can cause changes in odor and flavor, and, therefore, they should be used in the lowest possible concentration. However, the concentration must be sufficient for the action of interest: antioxidant or antimicrobial activity, increase in the shelf life of the product, among others. According to Moraes-Lovison et al. (54), this challenge can be overcome by using encapsulation and nanoemulsification techniques for the application of natural compounds. These alternative applications of essential oils and plant extracts in meat and meat products can be presented as an economically viable industrial alternative. These, in addition to the advantages already mentioned throughout the text, are low cost, depending on the polymers and plant materials used in the process, are easily produced and, in general, do not require high equipment costs (71,72).

CONCLUSIONS

Good results were obtained with essential oils and plant extracts when they were applied to beef, pork, goat and poultry. They acted by preserving the products, and, consequently, increasing the shelf life of the products. Antimicrobial and antioxidant activities were observed for the extracts and essential oils, and they are possible substitutes for synthetic additives. Many studies have suggested application methods that have a lower impact on the sensory characteristics of meat products, such as application in films, coatings, emulsions and nanoemulsions. However, studies aimed at alternatives for the application of these natural compounds with the objective of impacting the sensory quality of the products as little as possible must still be explored.

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**CONFLICT OF INTEREST**

The authors declare no conflict of interest.

**AUTHOR’S CONTRIBUTIONS**

Gabriela Aguiar Campolina: Developed the study concept; wrote the manuscript, conceptualization, methodology and writing - (review and editing);

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https://doi.org/10.1016/j.fbp.2019.06.001

https://doi.org/10.1016/j.fpsl.2018.06.011

https://doi.org/10.1111/1750-3841.14121

https://doi.org/10.1016/j.ijfoodmicro.2019.108493

https://doi.org/10.1016/j.fpsl.2020.100588

https://doi.org/10.17113/ftb.60.01.22.7144
https://doi.org/10.1007/978-0-387-89026-5_10

https://doi.org/10.1016/j.tifs.2011.02.004

https://doi.org/10.1111/lam.13782
Table 1. Essential oils as antioxidants and/or preservatives applied directly to meat and meat products

<table>
<thead>
<tr>
<th>Essential oil / Species</th>
<th>Majority constituent</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sage (Salvia officinalis)</td>
<td>NI</td>
<td>Direct</td>
<td>ATM (E. coli)</td>
<td>0.4 µL/g and 0.6 µL/g</td>
<td>Minced pork</td>
<td>14 days 4 °C</td>
<td>(22)</td>
</tr>
<tr>
<td>Oregano (Origanum vulgare)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cinnamon (Cinnamomum zeylanicum)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Tahiti lemon (Citrus aurantifolia)</td>
<td>NI</td>
<td>Essential Oil Emulsions and Nanoemulsions</td>
<td>ATM (C. sporogenes)</td>
<td>0.2325 % and 0.27 %</td>
<td>Mortadella</td>
<td>20 days 14 °C</td>
<td>(28)</td>
</tr>
<tr>
<td>Cardamom (Elettaria cardamomo)</td>
<td></td>
<td></td>
<td>NR and ANT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese pepper (Litsea cubeba)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Chinese pepper (Litsea cubeba)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Oregano (Origanum vulgare)</td>
<td>Carvacrol (77.19 %)</td>
<td>Direct combined with 0.5 and 1 % radish powder</td>
<td>NR</td>
<td>100 mg/Kg</td>
<td>fermented cooked sausages (pork/beef meat)</td>
<td>30 and 60 days 4 and 20 °C</td>
<td>(29)</td>
</tr>
<tr>
<td></td>
<td>Thyme</td>
<td>Rosemary (Rosmarinus officinalis)</td>
<td>ATMs and Direct Actions</td>
<td>Concentration (%)</td>
<td>Food Type</td>
<td>Shelf Life or Storage Conditions</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Thymol (50.48 %)</td>
<td>1,8-cineole (36.2 %) Camphor (16.4 %)</td>
<td>Direct/Spraying on packaging</td>
<td>0.3 %, 0.6 % and 0.9 %</td>
<td>Pork meat</td>
<td>15 days (3±1 °C)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ATMs (Salmonella (S. Enteritidis, S. Typhimurium, S. Montevideu e S. Infantis))</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ATMs (Pseudomonas spp., B. thermosphacta, Enterobacteriaceae)</td>
<td>4 %</td>
<td>Beef meat</td>
<td>20 days 4 °C Extended shelf life to up to 15 days; 4 to 5 more days</td>
<td></td>
</tr>
<tr>
<td>1- Zataria multiflora</td>
<td>1- Carvacrol (35.5 %), Thymol (22 %)</td>
<td></td>
<td>Direct/ANT (C. perfringens e C. sporogenes.) NR</td>
<td>1- 0.355 and 0.71 %</td>
<td>Beef meat</td>
<td>30 days T_{amb}</td>
<td></td>
</tr>
<tr>
<td>2- Origanum vulgare L</td>
<td>2- Carvacrol (29 %), γ-Terpinene (20 %)</td>
<td></td>
<td>Direct/ANT (C. perfringens e C. sporogenes.) NR</td>
<td>2- 0.395 and 0.79 %</td>
<td>Beef meat</td>
<td>30 days T_{amb}</td>
<td></td>
</tr>
<tr>
<td>3- Satureja bachtiarica</td>
<td>3- Carvacrol (46 %), Thymol (28.5 %)</td>
<td></td>
<td>Direct/ANT (C. perfringens e C. sporogenes.) NR</td>
<td>3- 0.275, 0.55 and 1.1 %</td>
<td>Beef meat</td>
<td>30 days T_{amb}</td>
<td></td>
</tr>
</tbody>
</table>

ATM: antimicrobial; ANT: antioxidant; NR: nitrite reduction; NI: not informed.
Table 2. Plant extracts as antioxidants or preservatives applied directly to meat and meat products

<table>
<thead>
<tr>
<th>Plant extract / Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sage (Salvia officinalis)</strong></td>
<td>Direct</td>
<td>ATM (<em>E.</em> coli)</td>
<td>0.4; 0.6 and 1.0 µL/g</td>
<td>Pork meat</td>
<td>14 days 4 °C</td>
<td>(22)</td>
</tr>
<tr>
<td>Olive leaves Green tea Stinging nettle</td>
<td>ε-polysine nanoparticles</td>
<td>ATM (<em>S.</em> aureus, <em>E.</em> coli, <em>C.</em> perfringens) ANT; NR</td>
<td>500 ppm (mixed extract)</td>
<td>Sausages</td>
<td>45 days 4 °C</td>
<td>(33)</td>
</tr>
<tr>
<td>Pomegranate peels (<em>Punica granatum</em>)</td>
<td>Direct</td>
<td>ANT</td>
<td>17.25 mg/Kg</td>
<td>Sausages</td>
<td>60 days 4 °C</td>
<td>(34)</td>
</tr>
<tr>
<td>Oregano (<em>Origanum vulgare</em>)</td>
<td>Direct</td>
<td>ANT</td>
<td>13.32, 17.79 and 24.01 mL/kg</td>
<td>Lamb burgers</td>
<td>120 days (-18±1) °C</td>
<td>(35)</td>
</tr>
<tr>
<td>Syzygium antisepticum</td>
<td>Direct application by dipping into the solution</td>
<td>ATM (<em>S.</em> aureus)</td>
<td>2; 8 and 32 mg/mL</td>
<td>Cooked chicken</td>
<td>5 days 4 and 10 °C</td>
<td>(36)</td>
</tr>
<tr>
<td><strong>Cinnamom Clave Anise</strong></td>
<td>Direct</td>
<td>Reduction of the accumulation of biogenic amines; ANT; ATM (total aerobic bacterial counts, <em>Enterobacteriaceae</em>)</td>
<td>0.3 g/kg</td>
<td>Harbin dry sausage (Pork meat)</td>
<td>9 days under fermentation</td>
<td>(37)</td>
</tr>
<tr>
<td>Pomegranate peels (<em>Punica granatum</em>)</td>
<td>Direct</td>
<td>ANT</td>
<td>0.5 % and 1.0 %</td>
<td>Beef meatballs</td>
<td>6 months – (18±1) °C</td>
<td>(38)</td>
</tr>
</tbody>
</table>
Purslane (Portulaca oleracea) & Pulverization & ANT e ATM (P. aeruginosa, B. subtilis e B. cereus) & 0.25 %, 0.50 % and 1.0 % & Pork meat & 9 days 4 °C & (39) \\
Olive leaves & Direct & Nitrite replacement & ANT ATM (total bacterial count; yeasts and molds) & 500 ppm (mixed extract) & Sausages & 45 days 4 °C & (40) \\
Guarana seed & Direct & ANT & 250 mg/kg, & Lamb burgers & 18 days (2±1) °C & (41) \\

ATM: antimicrobial; ANT: antioxidant; NR: nitrite reduction

Table 3. Essential oils as antioxidants or preservatives applied to meat and meat products in the form of films and coatings

<table>
<thead>
<tr>
<th>Essential oil / Species</th>
<th>Majority constituent</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyme (Thymus vulgaris L.)</td>
<td>Thymol (47 %)</td>
<td>Sodium alginate-based films - Micro and nanoemulsion</td>
<td>ATM (Coliforms; S. aureus; Lactic acid bacteria; molds and yeasts)</td>
<td>0.05 % and 0.04 %</td>
<td>Ground meat</td>
<td>8 days (4.0±1) °C</td>
<td>(44)</td>
</tr>
<tr>
<td>Lemon verbena (Aloysia citriodora)</td>
<td>Eugenol (14.63 %)</td>
<td>Sodium alginate-based coatings with and without modified atmosphere</td>
<td>ATM (Total bacterial count; Pseudomonas; Lactic acid bacteria; Psychrotrophic bacteria)</td>
<td>0.2 % and 0.5 %</td>
<td>Chicken breast</td>
<td>15 days in refrigeration</td>
<td>(17)</td>
</tr>
<tr>
<td>Clove (Syzygium aromati)</td>
<td>Eugenol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Name</td>
<td>Antioxidant (Composition)</td>
<td>Antimicrobial Activity</td>
<td>Material Type</td>
<td>Period (Temperature)</td>
<td>Result</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------</td>
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</tr>
<tr>
<td><strong>Rosemary (Rosmarinus officinalis)</strong></td>
<td>1.8-cineole (27.52 %), α-pinene (21.15 %)</td>
<td>ATM (Total count of psychrotrophic bacteria) 2 %</td>
<td>Whey protein isolate based film</td>
<td>Lamb meat 15 days (4.0±1 °C)</td>
<td>(45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zataria multiflora</strong></td>
<td>Thymol (37.94 %), Carvacrol (12.60 %)</td>
<td>ANT 6 %</td>
<td>Corn starch films</td>
<td>Ground beef patties 20 days (4.0±1 °C)</td>
<td>(46)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thymus kotschyanus</strong></td>
<td>Thymol (26.61 %), Carvacrol (12.60 %)</td>
<td>ATM (Pseudomonas, lactic acid bacteria e L. monocytogenes) 1 % and 2 %</td>
<td>Films based on corn starch and chitosan</td>
<td>Beef 21 days (4.0±1 °C)</td>
<td>(47)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Star anise (Illicium verum)</strong></td>
<td>Thymol (37.94 %), Carvacrol (12.60 %)</td>
<td>ATM (viable aerobic bacteria e E. coli) 0.4 % and 0.6 %</td>
<td>Coating based on soy protein isolate and lectin with nisin and pylylysin</td>
<td>Yao-Meat 20 days (4.0±1 °C)</td>
<td>(48)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cumin (Cuminum cyminum)</strong></td>
<td></td>
<td>ATM (Total count of bacteria, Enterobacteriaceae, S. aureus, E. coli, molds and yeasts); ANT 0.2 %, 0.4 % and 0.6%</td>
<td>Chitosan based coating</td>
<td>Chicken meat 9 days 4.0 °C</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Black cumin (Nigella sativa)</strong></td>
<td></td>
<td>ATM (S. aureus e E. coli) 1 %</td>
<td>Multilayer film based on chitosan and alginate</td>
<td>Chicken meat 5 days 4.0 °C</td>
<td>(50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ziziphora pérsica</strong></td>
<td>Pulegone (31.42 %), Neomenthol (18.58 %)</td>
<td>ATM (E. coli, S. Typhimurium, P. aeruginosa, L. monocytogenes, B. cereus, S. aureus) 0.5 % and 1 %</td>
<td>Alginate based coating</td>
<td>Chicken meat 12 days 4.0 °C</td>
<td>(51)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Type</td>
<td>Antimicrobial Activity</td>
<td>Concentration</td>
<td>Food Type</td>
<td>Shelf Life at Temperature °C</td>
<td>Reference</td>
<td></td>
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<tr>
<td>---------------------------</td>
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<td></td>
</tr>
<tr>
<td>Rosemary (Rosmarinus officinalis)</td>
<td>ATM (Aerobic bacteria mesófilas, B. cereus, S. aureus, L. monocytogenes, S. enterica, E. coli, C. albicans)</td>
<td>0.5, 1.0 and 2.0 %</td>
<td>Chicken meat</td>
<td>15 days (5.0±2) °C</td>
<td>(52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rosemary (Rosmarinus officinalis)</td>
<td>Nanogel encapsulation of benzoic acid and chitosan and applied as a coating</td>
<td>0.5, 1.0 and 2.0 mg of nanoencapsulated oils/g of meat</td>
<td>Beef cutlet</td>
<td>12 days 4.0 °C</td>
<td>(53)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oregano (Origanum vulgare)</td>
<td>Direct and nanoemulsion encapsulation</td>
<td>5 %</td>
<td>Chicken pate</td>
<td>8 days (4.0±2) °C</td>
<td>(54)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zataria multiflora</td>
<td>Chitosan-based coating with Sumac extract</td>
<td>1 %</td>
<td>Meat</td>
<td>20 days 4.0 °C</td>
<td>(55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satureja (Satureja khuzestanica)</td>
<td>Chitosan based coating</td>
<td>1 %</td>
<td>Lamb meat</td>
<td>20 days 4.0 °C</td>
<td>(56)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oregano</td>
<td>Pectin-based coating with resveratrol nanoemulsion</td>
<td>0.5 %</td>
<td>Pork loin</td>
<td>20 days 4.0 °C</td>
<td>(63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z. multiflora</td>
<td>Chitosan and gelatin based nanofibers</td>
<td>20 and 40 %</td>
<td>Sausage</td>
<td>20 days (4.0±1) °C</td>
<td>(64)</td>
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</tr>
</tbody>
</table>
Rosemary 
*(Rosmarinus officinalis)*

<table>
<thead>
<tr>
<th>Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitosan based films</td>
<td>ANT</td>
<td>2 %</td>
<td>Chicken meat</td>
<td>15 days (5.0±2) °C</td>
<td>(65)</td>
<td></td>
</tr>
</tbody>
</table>

Ginger 
*(Zingiber officinale)*

<table>
<thead>
<tr>
<th>Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polylactide films</td>
<td>ATM (S. Typhimurium, C. jejuni e L. monocytogenes)</td>
<td>25 % and 50 %</td>
<td>Chicken meat</td>
<td>21 days 4.0 °C</td>
<td>(66)</td>
<td></td>
</tr>
</tbody>
</table>

Cinnamon

<table>
<thead>
<tr>
<th>Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Films based on gelatin</td>
<td>ATM (total viable count, psychotrophic count, Pseudomonas spp., S. aureus, lactic acid bacteria, molds and yeasts)</td>
<td>0.24 %; 0.64 %; and 1 %</td>
<td>Beef</td>
<td>15 days 4.0 °C</td>
<td>(67)</td>
<td></td>
</tr>
</tbody>
</table>

Ajowan 
*(Trachyspermum ammi)*

<table>
<thead>
<tr>
<th>Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Films based on gelatin</td>
<td>ATM (total viable count, psychotrophic count, Pseudomonas spp., S. aureus, lactic acid bacteria, molds and yeasts)</td>
<td>0.24 %; 0.64 %; and 1 %</td>
<td>Beef</td>
<td>15 days 4.0 °C</td>
<td>(67)</td>
<td></td>
</tr>
</tbody>
</table>

ATM: antimicrobial; ANT: antioxidant; NR: nitrite reduction; NI: not informed.

### Table 4. Plant extracts as antioxidants or preservatives applied to meat and meat products in the form of films and coatings

<table>
<thead>
<tr>
<th>Plant extract / Species</th>
<th>Form of application</th>
<th>Effect</th>
<th>Dose used</th>
<th>Product</th>
<th>Storage conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pomegranate peel</td>
<td>Films based on corn starch and chitosan</td>
<td>ANT (Pseudomonas spp., lactic acid bacteria e L. monocytogenes)</td>
<td>0.5 % and 1 %</td>
<td>Beef</td>
<td>21 days (4.0±1) °C</td>
<td>(47)</td>
</tr>
<tr>
<td>Ingredient</td>
<td>Films/Coating</td>
<td>ANT SP</td>
<td>Ground/Beef</td>
<td>Temperature</td>
<td>Days/Cold</td>
<td>Reference</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------------------------------</td>
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</tr>
<tr>
<td>Red cabbage</td>
<td>Films based on starch and whey</td>
<td></td>
<td>Ground beef</td>
<td>4 days 4.0 °C</td>
<td>(57)</td>
<td></td>
</tr>
<tr>
<td>Laurel</td>
<td>Whey protein isolate based films</td>
<td></td>
<td>Cooked meatballs</td>
<td>60 days -18.0 °C</td>
<td>(58)</td>
<td></td>
</tr>
<tr>
<td>Laurel (Laurus nobilis L.)</td>
<td></td>
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</tr>
<tr>
<td>Sage (Salvia officinalis)</td>
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<td></td>
</tr>
<tr>
<td>Sumac (Rhus coriaria)</td>
<td>Chitosan-based coating with OE from</td>
<td>ANT e ATM</td>
<td>(total mesophilic</td>
<td>Beef</td>
<td>20 days 4.0 °C</td>
<td>(55)</td>
</tr>
<tr>
<td>Shatavari (Asparagus racemosus)</td>
<td>Edible film based on calcium alginate and</td>
<td>ANT e ATM</td>
<td>(total bacterial</td>
<td>Salsages</td>
<td>21 days (4.0±1) °C</td>
<td>(59)</td>
</tr>
<tr>
<td></td>
<td>maltodextrin</td>
<td></td>
<td>and yeast and</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>mold counts)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stinging nettle</td>
<td>e-polylysine coating</td>
<td>AN, ATM</td>
<td>(molds and yeasts,</td>
<td>Beef</td>
<td>12 days 4.0 °C</td>
<td>(60)</td>
</tr>
<tr>
<td>(Urtica dioica)</td>
<td></td>
<td></td>
<td>total bacterial</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>and coliform counts)</td>
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<tr>
<td>Grape seed</td>
<td>Chitosan-gelatin based coating</td>
<td></td>
<td>Pork</td>
<td>20 days 4.0 °C</td>
<td>(61)</td>
<td></td>
</tr>
<tr>
<td>Green tea</td>
<td>Organic based film</td>
<td></td>
<td>Pork</td>
<td>14 days 4.0 °C</td>
<td>(62)</td>
<td></td>
</tr>
<tr>
<td>Saffron leaves</td>
<td>Films based on chitosan and methylcellulose</td>
<td>ATM (E. coli e S. aureus)</td>
<td>3 %</td>
<td>Lamb meat</td>
<td>3 days 25.0 °C</td>
<td>(20)</td>
</tr>
<tr>
<td></td>
<td>nanofibers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ATM: antimicrobial; ANT: antioxidant; SP: smart packaging
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**Fig. 1.** Possible cellular targets of antibacterial action by natural compounds

**Fig. 2.** Antioxidant action of carvacrol by transferring a hydrogen atom from the OH group