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Abstract

Aromatic plants are gaining importance in recent years as potential sources of natural food preservatives due to the growing interest in the development of safe and effective natural food preservation. The use of vegetal substances with antimicrobial and antioxidant properties to increase the shelf life in meat and meat products is a promising technology. Taking into account that the diet with antioxidant may be absorbed and prevent lipid oxidation and colour deterioration, the possibility of feeding animal diets contains aromatic and medicinal plant (as thyme leaf, rosemary and sage) as natural antioxidants and antimicrobials represent a very interesting opportunity to replace synthetic antioxidants. In this sense, herbs of the Labiatae family, such as rosemary and sage, have been extensively studied for antioxidant and antimicrobial activities in a variety of systems. This review gives an overview of the current knowledge and recent trends in the use of plant-derived compounds from aromatic and medicinal as antimicrobials and antioxidant in animal diet and its effect on meat quality, their potentials and challenges.

Keywords: aromatic plants, meat, animal diet, antioxidant, antimicrobial, meat quality

1. Introduction

Animal scientists have been interested in improving meat quality and product composition through the modification of the diet of animals. The possible use of nutritional strategies to improve quality of food products from livestock is a new approach that emerges at the interface of food science and animal science. These strategies have emphasized in the improvement of the oxidative stability, such as supplementation of animal with natural antioxidants to minimize pigment and lipid oxidation in meat or the alteration of nutritional profile, increasing the content of polyunsaturated fatty acid (PUFA). The consumption of meat (rich in saturated fatty acid)
is related with diseases such as some types of cancers and cardiovascular diseases (especially in
developed countries).

In this sense, in recent years, consumers’ pressure to reduce the composition and quality of
fat in meat has led to attempts to modify meat by dietary strategies [1]. The modification of
fatty acid profile of meat is to decrease saturated fatty acid and increase the ratio n-3: n-6 and
PUFA: SFA (>4).

Between the strategies used, meat can be modified by external addition in the elaboration
of meat or by the addition in the animal diet of ingredients considered beneficial for health,
where these ingredients are able to eliminate or reduce components that are considered harm-
ful. In this sense, several studies have shown that animal diet can strongly influence the qual-
ity of the meat.

For example, the stability of muscle foods further improves after the addition of food ingredi-
ents in diet of animals than the direct addition to the meat products, because the antioxidants
are deposited where it is most needed. In order to alter the oxidative stability of intact muscle
foods, the only technology available is the use of food ingredients in the diet. In these prod-
ucts, where natural antioxidants are added to the diet producing a nutritional alteration of
muscle composition, no additive declarations are required and are more label-friendly.

Taking into account all these considerations, recent changes in legislation controlling the use of
animal feed additives and the increasing demand of consumers for healthier meat products, if
possible free of chemical additives, have stimulated interest in bioactive secondary metabolites
as alternative performance enhancers.

2. Production of functional meat products

2.1. Functional meat products

Meat and meat products are essential for a balanced diet, although it must also be remem-
bered that they are susceptible to modifications to give them a ‘healthier’ appearance.
Numerous studies have demonstrated the possibility of changing the image of meat and
meat products from the traditionally accepted image to one of healthy living thanks to the
modification of animal diet, addition (vegetables, extracts, fibres, herbs, spices, etc.), elimina-
tion (fats) and reduction (saturated fatty acid, additives) of different ingredients. The object
of including functional ingredients in the case of meat is not only concerned with providing
it with certain desirable properties but also an attempt to change its image in these health-
conscious days.

However, meat has beneficial health effects, for example, regarding obesity, and it also has
satiating properties. This aspect is very important in the development of tasty and satiating
functional meat products.

Therefore, in meat, the modifications to which it may be subjected to confer functional properties
on it are based on modifications to the feed an animal receives or on postmortem manipulation
of the carcass. Therefore, through the modification of animal diet, the lipid, fatty acid, and vitamin E content can be changed [2].

In the market of functional food, rapid progress has been made in the development of this kind of food, based on the results of studies on food components providing positive health benefits over and above normal nutritional benefits. Although many books and reviews on functional foods have been published, few of them have emphasized in the functional properties of meat and meat products (examples of functional properties of foods are anticarcinogenicity, antimutagenicity, antioxidative activity and antiaging activity). By modification of animal diet with the introduction of bioactive compounds, it should be possible to develop new meat products with potential health benefits. Such meat products would open up a new market in the meat industry.

2.2. Dietary supplementation of functional ingredients

2.2.1. Natural antioxidants

Fresh meat is mainly packed unprocessed and refrigerated. Currently the most widely used method in the marketing of fresh meat is packaging under modified atmosphere, both in the form of vacuum packaging and gas mixtures of known composition. The short shelf life of packed fresh meat is one of the principal concerns for its marketing. Lipid composition is a major determinant in the susceptibility of meat to oxidative changes and rancidity, leading to warmed-over flavours [3]. The quality attributes of meat products deteriorate due to the lipid oxidation during processing and storage. Lipid oxidation is responsible for development of primary and secondary oxidation products (short-chain aldehydes and ketones), reduction in nutritional quality, as well as changes in flavour, which can precipitate economic losses in terms of inferior product quality. The compounds formed after oxidation may adversely affect the overall quality and acceptability of meat and meat products (changes in flavour, texture and nutritional value).

In addition, the oxidative stability also affects the meat proteins. Specifically, the oxidation of indispensable amino acid reduces their digestibility and availability, and the tenderness of meat [4]. In addition, the oxidizable components of meat need to be protected from damages caused by the reactive oxygen species (ROS). The protection could be provided naturally through the deposition of antioxidant compounds derived from the feeds into the animal tissues.

Regarding meat storage stability can be extended with opportune packaging systems, by the exogenous addition of antioxidants or by adopting feeding systems able to improve the antioxidant status of muscle [4].

The rate of lipid oxidation can be effectively retarded by restricting the access to oxygen during storage vacuum-packaging and by the use of antioxidants that can be synthetic or natural: synthetic antioxidants were widely used in the meat industry, but consumer concerns over safety and toxicity pressed the food industry to find natural sources [5].

As alternative, synthetic antioxidants can be used natural extract from plant as grape, olives, sesame seed, tea, soybean, rosemary, thyme, etc with antioxidant properties [6]. Phenolic-rich
planted materials or extracts used as dietary supplement or added to meat products exerted anti-
oxidant properties by inhibiting lipid and protein oxidation in meat [7–9]. Studies reported that dietary antioxidant prevents colour deterioration and lipid oxidation [10–11].

Antioxidant compounds are usually added at a moderate dosage level since high level of inclusion may mechanistically cause adverse effects through pro-oxidative action [12]. Several studies have indicated that the modification of animal diet alters the oxidation of the meat (e.g. studies with lambs). The value of lambs lies in their ability to use low-quality feeds, in a sense upgrading low-quality inputs to high-quality outputs [13]. Santé-Lhoutellier et al. [14] studied the influence of diet on lamb meat oxidation and founds that the oxidative stability of lamb meat clearly depends on diet.

Scerra et al. [15] compared ewe’s diet with pasture or concentrated and showed an increase in the PUFA content in intramuscular fat lamb fed with pastures. Nieto et al. [16] showed an increase in PUFA content of lamb meat fed with thyme compared with control diets. Elmore et al. [17] reported the same increase of PUFA in lamb meat after inclusion of diet fish in the diet. Similarly, Bas et al. [18] and Ponnampalam et al. [19] reported increases in the content of long-chain n-3 fatty acids in lamb meat with the diet of linseed or fish oil, respectively.

Including herb distillates into livestock diets can have positive effects. Moñino and others [13] reported that inclusion of herb distillates (distilled rosemary leaves) into pregnant ewes diet increased carbonic acid, carnosol and rosmarinic acid in the lamb meat. Fresh lamb meat from distilled rosemary diet presented lower DPPH values and higher total ferric reducing antioxidant power, indicating that rosemary reduced lipid oxidation. Another studies in pigs reported similar results [20].

In addition, Simitzis et al. [21] found that meat from lambs fed a feed that had been sprayed with oregano essential oil (1 mL/kg) was much more stable to lipid oxidation during both refrigerated and frozen storage than that from controls. Boler et al. [22] found that feeding vitamin E to pigs increased pork stability during storage. Gobert et al. [23] reported a synergism effect in the combination of plant extract rich in polyphenols and vitamin E.

2.2.2. Conjugated linoleic acid

Interests in conjugated linoleic acid (CLA) have increased in the last decades as a result of its potential effects on human health-related benefits and animal production, as a result of the effects of dietary CLA to increase the animal performance, improve meat quality and provide meat products with high amounts of CLA.

Inconsistent results have been reported about the effects of dietary CLA on the growth, body composition and meat quality. Different animal species, different breeds, age, duration and levels of CLA, husbandry conditions and the composition of feed could explain these conflicting results [24].

Conjugated linoleic acid has been studied in many animal models to determine its effects on lipid metabolism, as trans-10, cis-12 is known to reduce adipose deposition. In the mouse model, CLA in the diet has been found to increase metabolic rate and fatty acid oxidation
while reducing fatty acid synthesis, lipoprotein lipase activity and division and differentiation of adipocytes [25]. Study by Wynn et al. [26] found a 36-fold increase in muscle trans-10, cis-12 CLA when a source of CLA (containing similar amounts of cis-9, trans-11 and trans-10, cis-12 isomers) was fed to growing lambs at 100 g/kg DM (approximately 50 g/kg DM of each isomer). They also found a 2- to 5-fold increase in cis-9, trans-11 CLA and a 3- to 20-fold increase of trans-10, cis-12 CLA in liver and adipose tissues.

It is generally accepted that dietary CLA can improve the body composition through reducing fat deposition and backfat thickness. In pigs, the fat deposition was reduced and the ratio of lean to fat increased linearly as the dietary CLA increased [27]. Dietary CLA not only reduced fat deposition but also altered the fatty acid composition of tissue lipids. In the study of Szymczyk et al. [28], the proportion of saturated fatty acids such as palmitic and stearic acids increased significantly, while that of monounsaturated and polyunsaturated fatty acids including palmitoleic, oleic, linoleic and arachidonic acid in broiler chickens decreased significantly.

In addition, other studies have shown that dietary CLA could increase the concentration of CLA in muscle and adipose tissues of chicken. Du and Ahn [29] reported that the amount of total CLA increased from 0 to 10.51 and 17.75 mg/g lipids in broiler breast muscle after 5 weeks of feeding 2 and 3% CLA. Therefore, feed nonruminant animal with synthesized CLA changes the fatty profile. These studies show that supplementation of CLA in the diet could be a strategy for developing a value-added meat product.

2.2.3. Vitamin E

Supplementation with vitamin E in animal diet improves meat quality by limiting lipid and protein oxidation [30–32]. Guidera et al. [32] reported an improvement in colour stability in lambs receiving with 1000 mg α-tocopherol/kg feed compared with non-supplemented feeds. Rowe et al. [33] showed that dietary vitamin E decreased the levels of protein oxidation and its influence on beef tenderization. Other study about texture of meat reported that the diet supplementation with 1000 IU vitamin E caused lower shear force in beef steaks from longissimus dorsi after 14 day of postmortem storage [34].

In addition, the effects of dietary vitamin E on drip loss were inconsistent: in poultry, dietary vitamin E inhibited the development of PSE conditions induced by heat stress resulting in improved meat quality [35].

Some studies have indicated a possible role for high doses of vitamin E in preventing shifts in PUFA biohydrogenation pathways [36, 37], thus minimizing any negative effect of plant oil on milk production, milk fat yield and/or milk fatty acid composition. Vitamin E could act either as an inhibitor of bacteria producing trans-10 C18:1 [37] or affect the accumulation of biohydrogenation intermediates in rumen fluid and CLA content [38].

The supplementation of ewes and lamb diet with Vitamin E [39, 40] is usually carried out by using a synthetic source of α-tocopherol (all-rac-α-tocopheryl-acetate), due to its stability and lower cost in animal feeds [41]. Another vitamin E source is RRR-α-tocopheryl-acetate, which is a derivate from vegetable oils and exhibits higher biological activity than synthetic vitamin
Recent studies in dairy cows have estimated that the relative bioavailability of vitamin E from natural sources is 1.36 times greater than that of synthetic vitamin E [43].

2.2.4. Omega-3 (ω3) fatty acids

Omega-3 PUFA consumption reduces the risk of cardiovascular disease [44] and inhibits the growth of mammary and prostate gland tumours [45]. It also delays the loss of immunological functions and is required for the normal foetal development of the brain [46]. PUFA is essential constituents for the development and growth of animal. In this group, docosahexaenoic acid (DHA, 22:6), docosapentaenoic acid (DPA, 22:5) and eicosapentaenoic acid (EPA, 20:5) are included.

It is possible to obtain enhanced n-3 PUFA meat, including the diet different raw materials such as linseed, chia (*Salvia hispanica*) or its oils and fish meal or other sea products [47].

One of the most important strategies in nonruminants is the inclusion of marine sources of n-3 PUFA and the study of product quality. For example, fed pigs or poultry with cereal-based diet increase n-3 PUFA and n-6 PUFA.

Coates et al. [48] reported that regular consumption of ω3 fatty acid-enriched pork can decrease the content of serum triglycerides and increase the production of serum thromboxane, and thus, it can reduce cardiovascular diseases. There are many other alternative food sources rich in long-chain PUFA available, and they include meat, milk and eggs from animals fed with ω3-enriched diets [49].

Crespo and Esteve-García [50] studied the inclusion of 10% olive oil, sunflower oil and linseed oil in broiler chickens for 20 days before slaughter. They showed highest n-3 PUFA and more favourable n-6:n-3 ratio in broilers fed with linseed oil, highest C18:1 in chicken fed with olive oil and highest proportion of linoleic acid in chicken fed with sunflower oil. Therefore, poultry diet with plant oils reported significant changes in the SFA, PUFA and MUFA content of abdominal fat of chicken. Similarly, Lu et al. [51] reported significant increase in C18:2 and C18:3 content in meat from pigs fed with soybean oil and linseed oil, respectively.

In addition, duration of feeding and time influences in the transfer of n-3 long-chain polyunsaturated fatty acids were found to be influenced by time and duration of feeding and the presence of other oil supplements. Haak et al. [52] studied the effect of inclusion of linseed or fish oil into the diet of pigs and concluded that a direct dietary source of DHA was required to increase DHA in animal muscle and that levels in pork could not be substantially influenced by dietary supply of precursors.

In addition, Lopez-Ferrer et al. [53] demonstrated that inclusion of rapeseed oil and linseed oil into the diet increased linoleic acid (used to synthesize w-3 PUFA).

Few studies have demonstrated that the oxidation of muscle from animal-derived enriched in n-3 PUFA is higher: for example, studies are made in rabbit meat [54–57], lamb meat [58], poultry [59] and pigs [60].
In order to avoid the higher tendency to oxidation in meat rich-PUFA, is recommended adding antioxidant in animal diet [61]. Therefore, the incorporation of the natural ingredients with antioxidant properties into the feed could be an interesting strategy to prevent oxidation of the meat [62-67].

2.2.5. Selenium

In many countries, there is a deficiency of selenium intake. The recommendations for selenium (60 and 75 μg/day for adult female and male in UK) are not covered by diet. Thus, the strategies to improve human selenium intake are the production of selenium-rich foods (eggs, milk and meat) with selenium supplementation in the animal diet or intake of selenium supplement capsular form.

Particular interest in selenium has been generated as a result of clinical studies showing that dietary supplementation with organic selenium, in the form of yeast grown on a media enriched with this trace element, decreased cancer mortality twofold [68]. Selenium is an essential trace mineral for human and animal because it is involved in regulating various physiological functions as an integral part of selenoproteins. Additionally, inadequate selenium consumption is associated with decreased fertility, genetic defects and poor health [69].

Various types of meat are important natural sources of selenium in human nutrition [70]. The selenium concentration in meats depends of selenium supplements used and geographical origin [71, 72]. Indeed, it is well established that selenite or selenate dietary supplementation is not effective in increasing selenium concentration in the meat. The main form of selenium in muscles of animals fed on grain-based diet is Se-Met, animals cannot produce this form of selenium Se-Met, and it must be in the diet. The form of selenium found in breast and muscle of chicken fed with high doses of selenium yeast is Se-Met. Therefore, only the organic selenium (in the form Se-Met) in cattle, pigs or chicken can increase the selenium concentration in the meat.

**Pork**: Producing selenium-enriched pork is reported in several studies. Kim and Mahan [73] compared the effects of supplementation dietary of inorganic and organic selenium in pork. These authors shown that selenium concentration in loin increased from 0.154 to 3.375 mg/kg with organic selenium supplementation. In addition, to increased selenium level, good colour, low drip loss, reduced pig odour, chewy and tender improved in final meat [74]. This selenium pork is available in Korea and Canada.

**Beef**: It is considered the major source of dietary selenium. However, there is a variation of concentration depending on country. For example, in USA, the selenium content in beef is higher than in Europe. This content of selenium can be increased with the addition of organic form into the diet of cattle [75].

**Lamb**: It can also be enriched with organic selenium into the diet. In this sense, Bierla et al. [76] reported that 100 g of selenium lamb reported 50% of recommendation of selenium per day.

**Chicken**: As in the case of beef and pork, the inclusion of selenite increases moderately the selenium level. Therefore, the use of organic selenium into the diet is necessary in order to
increase the levels in meat [77]. There is a commercial option of chicken-enriched selenium called ‘Selen Chicken’ in Korea. In Ukraine, a combination of selenium and Vitamin E is added to commercial chicken meat [78] in order to produce selenium-enriched meat and improves meat quality during storage.

Turkey: The option of producing selenium-enriched turkey meat is available in USA where the high levels (around 34 g/100 g) are obtained by using organic selenium in the diet and the soil rich in selenium [79].

These increased selenium contents in meat products can be an excellent way to improve selenium status and safe for people living in selenium-deficient areas.

2.2.6. Plants, fruits, herbs and spices

As alternative, synthetic antioxidants can be used for plants, fruit, herbs or spices as carob, citrus pulp, algae, grape, olives, sesame seed, tea, soybean, rosemary, thyme, etc. Phenolic-rich plant materials or extracts are used as dietary supplement or added to meat products exerted antimicrobial and antioxidant properties.

Carob: Gravador et al. [80] studied the modification of fatty acids and oxidative stability of meat from lambs fed carob-containing diets. Previous studies showed that growth performance in lamb is compromised when a level of carob higher than 45% is administered into the animal diet [81]. Therefore, in this study, either 24 or 35% carob pulp was used in the diets in the current study in order to assure similar lamb growth performances compared to a conventional barley-based diet.

Citrus pulp: Several studies have reported an improvement of meat oxidative stability in response to the administration of citrus-pulp diets. Taking into accounts that citrus fruits can be processed to obtain juices, a substantial amount of by-products originates. Among these, the dried citrus pulp is widely used for ruminant feeding, and for its favourable nutrient composition, it can replace high proportions of cereal concentrates in the diet with no detrimental effects on animal productivity. Citrus fruits contain high levels of bioactive compounds, including polyphenols, terpenes, carotenoids and ascorbic acid, which exhibit antioxidant properties [82]. Therefore, the study of Insera et al. [7] studied the effect of inclusion dried citrus pulp in the diet of lamb on the meat oxidative stability. These authors concluded that including high levels of dried citrus pulp in diets for intensively reared lambs might represent a feasible strategy to decrease the amount of cereal concentrates without compromising animal performances and to naturally improve meat oxidative stability.

The bioactive compounds (phenolic compounds) originating from the citrus fruits may cause the protective effects of dietary citrus pulp, against oxidation of lipid and meat proteins. Gladine et al. [83] showed that, after the dietary administration of a citrus extract to sheep, naringenin was detected in plasma and was able to increase its resistance to lipid peroxidation. Therefore, some of bioactive compounds in citrus are bioavailable in ruminants. Citrus pulp, which otherwise is just an agricultural waste, could find a valuable application in small ruminant feeding as a natural and cheap alternative to cereal concentrate feedstuffs with an ultimate positive impact on meat protein oxidative stability.
Algae are the original sources of DHA [84]. Several studies reported the inclusion of algae in animal feed in order to improve DHA content in eggs [85, 86] and chicken meat [87].

In this sense, the study of Delles et al. [88] investigated the influence of dietary algae and selenium (organic or inorganic) on quality of chicken meat. The results indicate that feeding diets with high-oxidized oil increased the vulnerability of lipids and proteins to oxidation and reduced the activities of tissue antioxidant defence enzymes. However, the dietary supplementation with an algae-based Se yeast and organic mineral antioxidant blend negated these effects. Furthermore, dietary antioxidant supplementation imparted a protective barrier against oxidation of broiler breast meat under HiOx, PVC, and SK packaging conditions throughout retail display. The improved oxidative stability appears to be associated with enhanced cellular antioxidant enzymatic activity and reduced ROS propagation in vivo. A more limited number of studies have looked into the effects of dietary supplementation with DHA-rich marine algae on the fatty acid composition of muscle tissue of pigs [89, 90].

Herbs and spices: Some herbs of the Labiatae family, particularly rosemary and sage, have been extensively studied for their antioxidative and antimicrobial activity. The vegetation in Southeast Spain is richer in aromatic plants than any other place in Europe. The province of Murcia is a major importer and processor of medicinal herbs. Rosemary and thyme are the most exploited, and their use mainly being the extraction of essential oils, a process that generates an excess of distilled leaves. These products are currently underused but could be used as potential sources of natural antioxidants and antimicrobials in the food industry.

Rosemary is the only spice commercially available for use as an antioxidant in Europe and the United States. Its extract contains antioxidant compounds, the most active being phenolic diterpenes such as carnosic acid, carnosol, epirosmanol, isorosmanol, methylcarnosate and rosmarinic acid [91]. These compounds have been shown to help prevent oxidation.

Thyme essential oil (EO) contains more than 60 ingredients, most of which posses important beneficial effects, for example, antiseptic, carminative, antioxidant and antimicrobial properties. The most important compounds of thyme EO are the phenols thymol (68.1%) and carvacrol (3.5%), which constitute the major and most active constituents, as well as the monoterpenes p-cymene (11.2%) and γ-terpinene (4.8%), which are known to have antioxidant properties and slow antimicrobial activity. The antibacterial properties of these compounds are in part associated with their lipophilic character, leading to their accumulation in membranes and to subsequent membrane-associated events such as energy depletion. Moreover, the (poly)phenolic compounds are characterized by having redox properties, which allow them to act as reducing agents, hydrogen donors, singlet oxygen quenchers and also as metal chelators.

Essential oil and extracts from Labiatae herbs have been successfully used in a wide variety of foods with good results as far as oxidative deterioration is concerned: for example, in turkey products [92], beef [93], pork [94], chicken [95], hens [96], lamb [13, 97–99] and in
vitro system [100]. In contrast, unsatisfactory results have been obtained in others cases. For example, Galobart et al. [101] and O’Grady et al. [102] concluded that a diet supplemented with rosemary did not affect the lipid stability of eggs or fresh meat.

3. Current status on the consumers acceptance and market for functional meat products

Regarding diversity in enriched poultry products, it is interesting to note that selenium-enriched eggs are already commonly seen on supermarket shelves in the Ukraine and Belarus. Selenium enrichment of eggs, meat and milk may be viewed as merely production of naturally designed food ingredients.

Indeed, production and commercialization of functional meat products have already opened a new era in supplementation of animals and have provided a real chance for producers to differentiate and add value to meat poultry products and to meet the increasingly diverse requirements of consumers.

There is a lack of studies on the effect on human health and safety of these meats. By that reason, the European food authorities are reluctant to promote the consumption of functional foods. However, the consumers have been accepted the link between health and food, and the responsibility of researcher and food authorities is to ensure that new functional meat products and products are healthy and safe. Promoted studies in this sense could lead to the development of differentiated meat products and meat with potential human health benefits, for example, promote the use of antioxidants that are components with nutraceutical and maintain the product safety of foods.

4. Conclusion and future prospects

The possibility to produce new animal-derived products with specific nutrients that promote health and improve the diet of consumers is a real target.

These animal-derived products are development with the same sensory characteristics that the only difference is the amount of specific nutrients. No modifications of traditions or eating habits of populations are produced, and these foods are cooked and consumed as usual. Therefore, without any modification of consumer’s habits, problem related with deficit of various nutrients (e.g. selenium) can be solved.

The main difficulties in the market of functional meat products are consumer’s idea that consumption of meat is unhealthy. However, consumers of many countries accept other animal-derived products as healthy food (e.g. milk and dairy products). Thus, more studies are necessary to demonstrate and afterwards inform consumers the functional value of meat.
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