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Potential Benefits of Plant-Derived Products on Broiler Meat Characteristics - A Short Review

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ABSTRACT

Herbal supplements have been researched for decades as a safe alternative to synthetic antioxidants. These natural supplements may help broilers enhance their meat quality, growth, and physiological circumstances. The phenolic compounds in herbal products can serve as antioxidants, thereby responsible for lessening the negative effect of stress before slaughter. One of the most critical factors impacting broiler meats' physical, chemical, and oxidative stability is stress before slaughter. Reducing stress levels during rearing may be anticipated to enhance broiler meat qualities. Some studies have found that herbal supplementation improves meat qualities, whereas others have no impact. The efficacy of herbal supplementation on meat characteristics may be determined by the nature and levels of herbal supplementation and the condition of the animals throughout the rearing. The use of plant-derived products in broiler production and their impact on carcass characteristics, physical and organoleptic qualities, chemical compositions, and oxidative stability of broiler meats are covered in this review.

Key words: antioxidant, herbs, meat quality, stress

INTRODUCTION

The demand for animal protein across the countries continues to rise over the year, owing to the country's growing population. The broiler chicken industry plays a critical role in supplying animal protein demand, mainly because the price of broiler chicken meat is lower than that of other animal protein sources. Despite its low cost, broiler chicken meat is favored by most people. This appears to be due to many causes, one of which is promoting chicken meat as a healthier meat choice. Indeed, recommendations to lower the risk of cardiovascular disease have been centered on dietary and lifestyle modifications, including advice to decrease red meat consumption while enhancing chicken meat consumption (Higgins & Thom, 1989).

The physical, organoleptic, and chemical characteristics and oxidative stability are critical indicators of broiler meat quality. Several factors have been reported to affect the nutritional aspects of broiler meats, including diets, rearing management, and stress (Mir et al., 2017). Modern broiler strains are particularly vulnerable to focus as they are typically raised intensively (at a high density). Indeed, the increased temperature, humidity, and ammonia in broiler houses with high stocking density may lead to uncomfortable conditions for broilers. An intensive rearing system may also limit the expression of normal behavior, which eventually end up in stress condition in broiler chickens (Sugiharto, 2016). In general, stress before slaughter has been associated with compromised broiler meat quality (Mir et al., 2017; Ashour et al., 2020). Stress conditions may alter glycogen stores in muscle, determining the physical and chemical contents of broiler meats after slaughter (Warriss et al., 1988).

Moreover, stress may influence postmortem glycolysis, resulting in pH changes and muscle protein denaturation during storage (Scheffler et al., 2013). Synthetic antioxidants have long been utilized in broiler production to deal with stressful situations. However, because of the chemical residue in broiler meats, long-term usage of synthetic antioxidants may be detrimental to human health (Sugiharto et al., 2019). Natural antioxidants, such as herbal supplements, have been used to reduce the adverse effects of stress on broilers' physiological and health conditions and meat quality. The application of herbal products or plant-derived products on broiler chickens and their possible impacts on carcass traits, physical and organoleptic rates, chemical compositions, and oxidative stability of broiler meats are discussed in this present review.

Meat Characteristics of Broilers

Broiler meat is an essential source of protein, lipids, minerals, vitamins, and bioactive components, all of which have benefits for human health (Attia et al., 2017). According to Mir et al. (2017), proteins, lipids, and minerals are present in raw poultry meats in 18.4 to

23.4%, 1.3 to 6.0%, and 0.8 to 1.2%,respectively. In general, broiler meat has a low fat and cholesterol content, with only around 1% fat in the leanest cut (such as breast meat) and 17% fat in cooked wings with skin (Marangoni et al., 2015). In the latter case, the incorporation of skin can raise the fat content of broiler meat. In terms of nutritional value, chicken fat has a nutritionally beneficial composition. When compared to red meat (beef or pork), broiler meat is high in monounsaturated fatty acids (MUFA), with saturated fatty acids (SFA) accounting for only one-third of total fat and a significant amount of polyunsaturated fatty acids (PUFA), particularly n-6 linoleic acid and arachidonic acid (Hibbeln et al., 2006; Marangoni et al., 2015). Broiler meat may also be a significant source of long-chain n-3 fatty acids, and hence increasing broiler meat consumption is not linked to an increased risk of coronary heart disease (Givens et al., 2008). Moreover, Mir et al. (2017) documented that chicken meat has no trans-fat, unlike beef and dairy fat, which leads to coronary heart disease. Roughly half of the fat is made up of beneficial monounsaturated fats, with just a third of the fat being made up of the less healthy saturated fats (Mir et al., 2017). Other than chemical/nutritional compositions, other determinants of broiler meat quality are physical and sensory or organoleptic characteristics. These include color (appearance), texture, water holding capacity (WHC), drip loss, cooking loss, pH, and flavor (Mir et al., 2017).

From a human health and consumption standpoint, broiler meat's fatty acid compositions and antioxidants are essential (Sugiharto et al., 2010; Attia et al., 2017). The more significant content of long-chain PUFA in broiler meats is favorable, as it may beneficially affect consumers' health. However, the presence of such fatty acids may damage the oxidative stability of meats (Mir et al., 2017). In addition to the loss of essential fatty acids and vitamins, oxidation processes result in changes in the color, texture, and appearance of rancid odor and flavor, impacting customer acceptability. Furthermore, lipid oxidation can produce many hazardous compounds detrimental to human health (Mir et al., 2017; Domínguez et al., 2019). The presence of antioxidants in broiler meats is necessary to prevent lipid oxidation. In this case, free radicals or catalysts that induce lipid oxidation in meats may be neutralized by antioxidants (Domnguez et al., 2019).

Meat characteristic is a multifaceted term impacted by many factors, including broiler strains, dietary composition, feed type, and additives/supplements. Rearing techniques, chicken health, environmental circumstances, slaughter practices, storage, handling, and cooking proce[6]es also impact broilers' meat quality (Attia et al., 2017). In agreement with this, Mir et al. (2017) documented that diet composition may determine the content of essential PUFA, especially the n-3 fatty acids in broiler m[2]ts. In line with this, Sugiharto et al. (2020a) reported that feeding a fermented mixture of cassava pulp and *Moringa oleifera* leaf meal increased the proportion of PUFA while lowering the fat content of broiler meats. Regarding meat PUFA, these fatty acids range can be raised more easily in poultry than in ruminant meats (Mir et al., 2017). This appears to be connected to poultry and ruminant animals (the fermentative process may alter the characteristics of diets or additives).

Effect of Plant-Derived Products on Carcass and Commercial Proportions of Broilers

Carcass and commercial cuts are critical factors in broiler production because they influence the rehead price of broiler chickens. The growth-promoting impact of herbal products on broilers has been documented in several studies, with dietary herbal supplementation leading to increased broiler final body weight (Aditya et al., 2017; Camy et al., 2019). The growth rate, final body weight, and carcass percentages of broilers are all known to be positively correlated (Narinc et al., 2015). For this reason, it could be understood that treatment with plant-derived compounds might result in higher dressing percentages and commercial cuts of broilers (Table 1). Recently, Sugiharto (2021) revealed that herbal supplementation improves nutrient digestibility in broilers, increasing the availability of nutrients for metabolism and energy for growth. The latter condition may also increase the conversion of dietary protein into body mass (protein) and thus increase the carcass percentage of broilers. The mechanism by which herbal supplements increase nutrient digestibility has been studied by Hafeez et al. (2020). They reported that some herbal products such as ajwain, fenugreek, and black cumin could enhance the digestibility of crude protein, fat, and nitrogen-free extract of broilers. It was

evident that herbal supplementation improved the intestinal ecology, health, and functions and improved the digestive and absorptive capacity of the intestine of broilers (Sugiharto, 2021).

Aside from the report showing the improving effect of plant-derived products on broiler carcass traits, Table 1 also offers some studies documenting the absent impact of some selected herbal supplements on carcass and commercial proportions of broilers. The efficacy of herbal supplements on broilers is very likely to be reliant on the types of plant-derived products, quality of raw herbs, possible contamination by harmful chemicals or toxic compounds, processing techniques and conditions of herbs, administration or delivery routes, packaging, storage conditions, and herbal supplement dosages (Sugiharto, 2021). Quality monitoring for raw herbs and herbal supplements and application on broiler chickens is required.

Table 1. Effect of plant-derived products on carcass and commercial cuts of broilers

Plant-derived products	Levels and delivery routes	Impacts	References
Neem leaves, garlic leaves, and plantain extracts	Each ten ppm in drinking water	Treatments with neem leaves and plantain extracts increased the dressing percentage of broilers	Camy et al. (2019)
Turmeric and rosemary essential oil	75 and 150 mg/kg diet	Supplementation increased carcass and thigh weight of broilers	Gharejanloo et al. (2017)
Decocted turmeric	25, 50, 75, and 100% of drinking water	At 75%, decocted turmeric increased breast weight of broilers	Isroli et al. (2017)
Herb extract (a mixture of honey and fenugreek, chamomile, nettle, thyme, mint, and black seed	0.2 and 0.3 mL/L drinking water	Treatments increased dressing percentages without affecting commercial cuts of broilers	Mudalal et al. (2020)
Superliv herbal formula (commercial product)	500 g/t feed	Supplement increased carcass weight of broilers	Lipinski et al. (2017)
Turmeric (*Curcuma longa*) powder	0, 0.5, 1.0 and 1.5% of diets	Treatment reduced abdominal fat content and at 0.5% increased the dressing percentage of broilers	Mondal et al. (2015)
Blueberry extract	0.5, 1 and 2% of diets	Treatments increased dressing percentages of broilers	Ölmez et al. (2021)
Commercial phytogenic extract herbs (AROMIX)	1 ml AROMIX per 5, 10, and 15-liter tap water	Treatment did not affect carcass and commercial cuts of broilers	El-Hady et al. (2020)
Onion (*Allium cepa*) extract	5, 7.5, and 10 g/kg basal diets`	Treatment did not affect carcass weight and the abdominal fat pad of the broiler	Aditya et al. (2017)
Herbal mixture (*Thymus vulgaris, Pimpinella anisum, Capsicum annuum, Mentha spicata, Salvia rosmarinus, Allium sativum*, and *Nigella sativa*) powder	2, 3, 4, 5, and 6 g herbal mixture/kg diet	The herbal mixture had no impact on carcass and commercial cuts of broilers	Ashour et al. (2020)
A mixture of oregano, chili, and cinnamon extracts	75, 150, and 225 ppm/kg diet	Treatment had no impact on carcass yield and commercial cuts of broilers	Carlos et al. (2014)

Effect of Plant-Derived Products on Physical and Organoleptic Characteristics of Broiler Meats

Physical and organoleptic characteristics have been essential for broiler meat quality and acceptance (Mir et al., 2017). The influence ofherbal supplements has been examined, and Table 2 shows some of the effects of herbal supplements on physical and organoleptic features. The physical properties of broiler meats improved as a result of herbal supplementation, including lower pH, lightness (L*), cooking loss, drip loss, and shear force, as well as higher water holding capacity (WHC) and redness (a*) values. Lower pH values have been linked to microbial growth inhibition in meat, preventing the decomposition or breakdown of meat components such as amino acids and fat, especially during storage (Mir et al., 2017; Ashour et al., 2020). It is important to distinguish between lowered pH values during storage and decreased pH early postmortem for meat pH. While changes in pH during storage are linked to microbial growth and thus meat decomposition, a quick postmortem drop in pH can result in a pale, soft, and exudative (PSE) state in meat with a pale appearance and lower WHC (Tashla et al., 2019).

In contrast to the decreased pH values caused by herbal supplementation (Shirzadegan & Falahpour, 2014; Ashour et al., 2020), another study found that herbal treatments caused broiler meat pH values to rise during storage (Jang et al., 2008). This difference was most likely due to muscle glycogen stores before slaughter. Before slaughter, stress and feed restriction have been identified as variables that decrease glycogen stores in broiler muscle (Warriss et al., 1988). It is worth noting that the lower glycogen muscle reserves may be attributed to the less conversion of residual glycogen into lactate during the storage, thus decreasing the pH values of meats. In this respect, the residual glycogen in the muscle may be the important factor determining the pH values of meats during the storing period (Scheffler et al., 2013).

Lightness (L*) is one of broiler meat's most important physical characteristics that may be attributed to PSE conditions. The lower pH and greater L* values of fresh broiler meats may lead to PSE meats. In such a case, meats with a pH of below 6.0 experience more protein denaturation, which results in more light scattering and opaqueness (Mir et al., 2017). Table 2 lists various research that indicates how herbal supplementation might reduce L* and increase a* values in broiler meats during early postmortem and storage. In this respect, Jang et al. (2008) showed that dietary oregano essential oil supplementation improves meat color (lower L* values) by decreasing hemoglobin oxidation and activating mechanisms that improve pigment distribution in chicken tissues. Aditya et al. (2017) discovered that onion extract effectively reduced meat oxidation. As a result of this condition, broiler meat will not be pale. In terms of increasing the b* and a* values of meats, Wang et al. (2017) suggested that herbal treatments may delay myoglobin oxidation, thus preventing muscle protein denaturation in broiler meats. Herbal treatment, on the other hand, increases hemoglobin in broiler tissue. In support of this, Sugiharto et al. (2011) suggested that turmeric extract (at the dose of 200, 400, 600, and 800mg/kg-live body weight) improved broiler digestion and metabolism, resulting in increased hemoglobin production and, therefore, broiler meat redness. Also, herbal supplements may enhance pigment deposition (especially yellow pigment) in broiler meats, as Sugiharto et al. (2020b) reported.

Treatment with herbal products has improved WHC and minimized drip loss or cooking loss (Table 2). These features have been related to the enhanced physical properties since increased WHC indicates that meat has a greater capacity to maintain its nutrients or protein content (Mir et al., 2017). Wang et al. (2017) reported that the higher antioxidant levels in broiler meat treated with herbal products might be responsible for the enhanced WHC. As a result of the improved antioxidative capacity of meats, nutrient oxidation, particularly protein oxidation, may be reduced (Surai, 2020). Reduced protein denaturation may, on the other hand, increase the WHC of broiler meats. Given the hydrophilic nature of the protein, lower proteolysis or protein denaturation in broiler meats fed with herbal products may be linked to better WHC, drip loss, and cooking loss (Wang et al., 2017). Overall, the improvement in water retention capacity may positively influence the flavor, texture, tenderness, and thus acceptability of broiler meats (Yang et al., 2020). The study showed that herbal supplementation was attributed to reduced white striping and white striping plus wooden meat incidences (Mudalal et al., 2020). In this regard, herbal treatment may

Table 2. Effect of plant-derived products on physical and organoleptic characteristics of broiler meats

Plant-derived products	Levels and delivery routes	Impacts	References
Herbal mixture (*Thymus vulgaris*, *Pimpinella anisum*, *Capsicum annuum*, *Mentha spicata*, *Salvia rosmarinus*, *Allium sativum*, and *Nigella sativa*) powder	2, 3, 4, 5 and 6 g/kg diets	Herbal mixture lowered pH and L* values while increasing a* values of broiler meats during storage	Ashour et al. (2020)
Mentha arvensis and *Geranium thunbergii* extracts	0.1% of drinking water	Treatment improved WHC, cooking loss, flavor, texture, and acceptability of broiler meats	Yang et al. (2020)
Acidified turmeric and black pepper powder	1% of diets	Treatments reduced the L* values of broiler meats	Sugiharto et al. (2021)
Herb extract (a mixture of honey and fenugreek, chamomile, nettle, thyme, mint, and black seed	0.2 and 0.3 ml/L drinking water	Treatments reduced white striping and white striping plus wooden meat incidences	Mudalal et al. (2020)
Garlic, black pepper, and hot red pepper	Each 0.5 and 1.0% of basal diets	Treatments improved sensory quality and physical characteristics (reduced L* values) of broiler meats	Tashla et al. (2019)
Marigold extract	0.075, 0.15, 0.30 and 0.60% of diets	The extract decreased drip loss and shear force while increasing the b* and a* values of thigh meats	Wang et al. (2017)
Scutellaria baicalensis extract	0.025 and 0.05% of basal diets	Treatment decreased drip loss of broiler breast meat	Park et al. (2016)
Schisandra Chinensis extract	0.1, 0.2 and 0.4% of diets	The extract decreased drip loss and shear force of broiler breast meats	Yan et al. (2013)
Dried rosemary leaves and rosemary volatile oil	Rosemary leaves (5.7, 8.6, and 11.5 g/kg feeds) and rosemary volatile oil (100, 150 and 200 mg/kg feeds)	Treatments improved meat colour and decreased pH values of broiler meats	Yesilbag et al. (2011)
Medicinal herb extract mix (mulberry leaf, Japanese honeysuckle, and goldthread)	0.3 and 1% of basal diets	Treatments increased pH and lowered L* values of meats during three days of storage	Jang et al. (2008)
Herbs extract mixture (Iranian green tea, cinnamon, garlic, and chicory)	2.5, 5.0 and 7.5% of diets	The extract reduced pH and increased the flavor and acceptability of broiler meats	Shirzadegan and Falahpour (2014)

improve consumer acceptance of broiler chicken meat. Petracci et al. (2019) pointed out that one of the factors inducing white striping and white striping plus wooden meats is the oxidative stress leading to tissue degeneration. Therefore, the efficacy of herbal supplementation in reducing such muscle degeneration and myopathic changes seems to be accounted to the antioxidative properties of plant-derived supplements.

Apart from the beneficial impacts of herbal supplementation, some studies have also shown the absent or detrimental effects of herbal treatment on the physical characteristics of boiler meats. For instance, Sukoco et al. (2015) reported that dietary inclusion of noni (*Morinda citrifolia* L.) leaves extract (at levels of 0.05, 0.10, 0.15, and 0.20%) did not affect physical quality, including pH, WHC, cooking loss andtenderness, of broiler breast meats. Several factors influence the physical characteristics of broiler meats; some of them are stress conditions before slaughter and pre-slaughter management (Sukoco et al., 2015; Fernandes et al., 2016). These latter factors may influence feed intake, digestion, and nutrient utilization, determining the glycogen stored in the muscle. Indeed, muscle glycogen storage may ultimately influence broiler meats' physical and chemical characteristics (Warriss et al., 1988). Other studies also reported that dietary incorporation of turmeric extract (2.5%), garlic extract (2.0%), and a combination of both reduced WHC of broiler meats (Purwanti et al., 2018). The latter investigators speculated that the low pH values of meat (primarily due to stress conditions before slaughter) seem to be responsible for the denaturation of protein myofibrils leading to low WHC in their study. Previously, Lohmann et al. (2021) also reported that dietary guavira fruit (*Campomanesia adamantium*) peel extract (100, 200, 300, 400, and 500 mg/kg feed) reduced thigh muscle redness 15 min after slaughter. It has widely been known that myoglobin is responsible for the redness values of meats. Myoglobin is easily oxidized to metmyoglobin, which may influence the meat's colour and quality. In most situations, polyphenols derived from plant products are expected to prevent or minimize the oxidation of myoglobin into metmyoglobin. However, the antioxidative functions of plant-derived polyphenols are impaired by their low bioavailability (Lohmann et al., 2021). This may explain the absent effect of herbal products on broiler meats' physical and chemical aspects. In other studies, Cross et al. (2011) reported that garlic powder at 1 g/kg changed broiler meats' flavor (into abnormal flavor). It was most likely that garlic may be incorporated into the muscle components, altering the normal flavor of broiler meats. Indeed, most flavor effects due to dietary treatment are mainly due to changes in fatty acid compositions of meats (Ba et al., 2012).

Effect of Plant-Derived Products on Chemical Compositions of Broiler Meats

The nutritive values of broiler meats have been a big concern and, therefore, determine consumers' preferences. Many factors may affect the nutritional qualities of broiler meats, one of which is the diet (Mir et al., 2017; Yang et al., 2020). In terms of feed additives or supplements, dietary herbal supplementations have been demonstrated to affect the chemical compositions of broiler meats (Table 3). The influences include an increase in total protein while lowering the crude fat contents of broiler meats. As mentioned above, herbal treatment has been documented to increase protein digestibility (Ibrahim et al., 2021; Sugiharto, 2021), which may increase protein deposition in the muscle of chickens. Dietary incorporation of herbal products has been associated with increased phenolic compounds in birds (Ibrahim et al., 2021). This increase in phenols has been reported to upregulate the gene expression of insulin-like growth factor-binding proteins, which may consequently increase muscle protein accretion (Johnson and Mejia, 2016). The increased gene expression of insulin-like growth factor binding proteins may also be attributed to the reduced rate of muscle protein breakdown in animals (Tomas et al., 1998). Likewise, the capacity of herbal products to increase the content of polyphenols in meats (Easssawy et al., 2016) has been accounted for the protection of meats from oxidation. Hence, meat deterioration, especially muscle protein, can be prevented (Yang et al., 2020).

In most situations, it has been suggested that the protein and fat contents of herbal-treated-broiler meats are inversely correlated (Easssawy et al., 2016). In this case, the upregulation of insulin-like growth factor binding proteins gene expression due to herbal treatment (Ibrahim et al., 2021) may be connected to the reduced fat content in broiler meats, as reported by Tomas et al. (1998). In other studies, Yang et al. (2013) suggested that herbal compounds may regulate the lipid metabolism in broiler chickens by inhibiting lipase activity. In this respect, fat digestibility derived from feed may be attenuated. Xie et al. (2019) have recently documented that feeding curcumin affected the [illegible] and lipolysis, including acetyl CoA carboxylase ( ),

1c), ATP-citrate lyase (ACLY), peroxisome proliferators-activated receptor α (PPARα) and carnitine palmitoyl transferase-I (CPT-I), resulting in decreased hepatic and plasma lipid profile of broiler chickens. Such a condition may consequently reduce the fatness in broilers. Fat deposition in broilers greatly depends on lipid oxidation and endogenous fatty acid synthesis. Dietary incorporation of herbal products has decreased fat concentration in broiler breast meats (Giannenas et al., 2018). This decrease has been attributed to the role of phenolic compounds in herbs that may inhibit endogenous fatty acids synthesis resulting in low-fat deposition in broiler meats, which agrees with Xie et al. (2019) as discussed above.

Table 3. Effect of plant-derived products on chemical compositions of broiler meats

Plant-derived products	Levels and delivery routes	Impacts	References
Quinoa seeds extract	10 and 30 g/100 kg diets	Treatment increased protein and reduced fat contents of breast and thigh meats	Easssawy et al. (2016)
Schisandra Chinensis extract	0.1, 0.2 and 0.4% of diets	At 0.2%, the extract increased the protein content of breast meats	Yan et al. (2013)
Mentha arvensis and *Geranium thunbergii* extracts	0.1% of drinking water	Treatment increased protein and decreased fat contents of broiler meats	Yang et al. (2020)
Neem leaves, garlic leaves and plantain extracts	Each 10 ppm in drinking water	Each treatment reduced the fat content of broiler meats	Camy et al. (2019)
Stresomix™ (β-caryophyllene and menthol)	0.5 g/kg feed	Treatments reduced the fat content of broiler breast meats	Giannenas et al. (2018)
Sumac (*Rhus coriaria*) fruit powder	2.5, 5.0 and 10 g/kg diets	At 10 g/kg, sumac fruit powder decreased the fat content of broiler meats	Saleh et al. (2018)
Sauropus androgynus leaf, bay leaf, basil leaf, papaya leaf, *Moringa* leaf, noni fruit powder	5% for each supplement	The herbs increased protein, iron, potassium, calcium, phosphorus, linolenic acid, methionine, n-3 PUFA while lowering fat, glutamic acid, alanine, lignoceric acid, oleic acid, and n-9 PUFA	Santoso et al. (2018)
Sauropus androgynus leaf extract plus turmeric extract	18 g *Sauropus androgynus* leaf extract plus 1 g turmeric extract/kg diet	Treatment lowered stearic acid and increased eicosapentaenoic acid in broiler meats	Kususiyah et al., 2019
Blueberry extract	0.5, 1 and 2% of diets	At 2%, blueberry extract improved the fatty acid composition of breast and thigh meats of broiler	Ölmez et al. (2021)
Pennywort powder	0.5% of basal diet	Supplement increased C18:3n-3 proportion in broiler meats	Ramiah et al. (2014)
Pomegranate pomace extract	0.1, 0.2 and 0.3 g/kg feeds	At 0.2 and 0.3 g/kg, the additive increased n-3 long-chain PUFA in broiler meats	Saleh et al. (2018)

The high content of n-3 long-chain PUFA in meats is preferable for the consumers, as this high content has been associated with a health-beneficial effect on humans. In monogastric animals including broiler chickens, the content of n-3 long-chain PUFA is easily increased through dietary treatments, which is quite different from ruminant animals (Mir et al.,

2017). Concerning dietary manipulation, supplementation of plant-derived products has been reported to increase the content of n-3 PUFA in broiler meats (Table 3). Ramiah et al. (2014) reported that the high content of n-3 PUFA in plant-derived products may be associated with the increased n-3 PUFA due to the deposition of n-3 PUFA derived from plant products into muscle. Also, Saleh et al. (2018) and Kususiyah et al. (2019) pointed out that phenolic components in herbal products may be associated with the inhibited PUFA oxidation in meats. This may consequently maintain the n-3 PUFA content in meats. In line with this, Camy et al. (2019) reported that herbal extract may function as a strong superoxide anion scavenger and a natural antioxidant for broiler chicken. Indeed, antioxidants may prevent auto-oxidation of n-3 PUFA. Aside from the PUFA, dietary inclusion of herbs has also reduced the cholesterol content of broiled meats as reported by Hartoyo et al. (2018) when using commercial "Fermeherbafit" (mixed herbs) on broiler chickens. Some bioactive compounds in herbal products such as allicin have been reported capable of reducing cholesterol in the meat of broilers. In agreement with this, Ramiah et al. (2014) suggested that allicin can inhibit the cholesterol synthesis in the body of broilers.

Apart from the studies reporting the beneficial effects of herbal products in improving the chemical characteristics of broiler meats, some studies have reported no meaningful effect of herbal supplements on the chemical variables of broiler meats. Shirzadegan & Falahpour (2014) used herbs extract mixture (i.e., Iranian green tea, cinnamon, garlic, and chicory) at 2.5, 5.0, and 7.5% of diets. They found no effect of such herbs on crude protein, crude fat, and moisture contents of broiler meats. Similarly, Ibrahim et al. (2021) included cornelian cherry extract in 50, 100, 200, and 400 mg/kg diets, and found no effect on crude protein and crude fat of breast and thigh meats broilers. Also, Hidayat et al. (2017) administrated liquid turmeric extract at 2, 4, 6, 8, and 10% in drinking water. At the levels of 8 and 10%, treatment reduced the water content of broiler meats. The differences in nature (bioactive compounds and their concentration) of herbal products, level of inclusion, diets, and experimental conditions (especially management induced stress before slaughter) may be responsible for the divergent results.

Effect of Plant-Derived Products on Antioxidative Activities of Broiler Meats

The shelf-life of broiler meats is one of the essential factors in the rehead market. In general, the shelf-life of meats is inversely correlated with oxidation that occurs during storage. Indeed, the oxidation may not only shorten the shelf-life of meats, but oxidation may also alter the color, odor/aroma, flavor, texture, and sensory properties of meats. Also, when biological molecules are oxidized, they produce harmful biological chemicals (carcinogenic and atherosclerotic effects) that can be detrimental to human health (Reitznerová et al., 2017). Traditionally, dietary antioxidants have been utilized to prevent the oxidation of meats during postmortem processing, extending the shelf-life and maintaining meat quality (Mir et al., 2017). However, the long-term usage of synthetic antioxidants in broiler production might cause cancer in humans (Sugiharto et al., 2019). Instead of synthetic antioxidants, the application of natural sources of antioxidants has been reported to improve the antioxidative activities or oxidative stability of broiler meats, and thus increase the shelf-life and quality of broiler meats.

Temperature, light, and oxygen are all variables that promote oxidation in meats. Fatty acid compositions and prooxidant substances might contribute to the development of oxidative processes in meats (Mir et al., 2017; Domínguez et al., 2019). Other variables that alter the fatty acid content of broiler meats may also indirectly impact the degree of oxidation. Rearing management (free-range or intensive production system) and diets are two factors (Domnguez et al., 2019). Regarding diets, herbal or plant-derived products have been documented to inhibit meat oxidation and avoid meat deterioration (Table 4). In the latter case, the reduced production of malondialdehyde (MDA) and thiobarbituric acid reactive substances (TBARS) in herbs-fed broiler meats during storage may represent the reduced meat oxidation. The increasing amount of phenols in meats decreases MDA and TBARS (Giannenas et al., 2018). In general, phenolic content is linked to antioxidant activity since it primarily involves antioxidant action (Sugiharto et al., 2016; Ashour et al., 2020).

For this reason, the increased phenols in meats may reasonably increase antioxidant activity, which eventually reduces oxidation in

meats. The enhanced total antioxidant capacity in herbs-fed broiler meats was also attributed to the increased superoxide dismutase (SOD) enzyme activity, which decreased MDA levels in the meats (Wang et al., 2017). Indeed, various enzymes, including superoxide dismutase (SOD), catalase, and glutathione peroxidase (GPx), can neutralize free radicals and reduce peroxidation.as a result, meat's oxidative activity and oxidative stability may be improved (Hosseindoust et al., 2020).

Table 4. Effect of plant-derived products on antioxidative activities of broiler meats

Plant-derived products	Levels and delivery routes	Impacts	References
Onion (*Allium cepa*) extract	5, 7.5 and 10 g/kg basal diets	Increasing onion extract levels linearly and quadratically decreased TBARS values of 10 days of stored breast meat	Aditya et al. (2017)
Herbal mixture (*Thymus vulgaris, Pimpinella anisum, Capsicum annuum, Mentha spicata, Salvia rosmarinus, Allium sativum* and *Nigella sativa*) powder	2, 3, 4, 5, and 6 g herbal mixture/kg diet	Herbal mixture decreased TBARS values of fresh meat and 7 and 15 days stored breast meat	Ashour et al. (2020)
Quinoa seeds extract	10 and 30 g/100 kg diets	Treatment increased total phenols and DPPH scavenging activity while lowering TBARS values of breast and thigh broiler meats	Easssawy et al. (2016)
Ethanolic extract of mango seed	200, 400, 600, 800 and 1000 ppm/kg diets	At a dose of 600 ppm or more, the extract increased the antioxidant capacity of meat-based on ABTS method	Farias et al. (2020)
Turmeric and rosemary essential oil	75 and 150 mg/kg diet	Treatment reduced MDA concentrations of 30 and 60 stored meats at -20°C	Gharejanloo et al. (2017)
Stresomix™ (β-caryophyllene and menthol), Ayucee™ (n-hexadecanoic acid and β-caryophyllene), and Salcochek Pro™ (menthol and clavicol methyl ether)	Stresomix™ (0.5 g/kg feed), Ayucee™ (1.0 g/kg feed) and Salcochek Pro™ (1.0 g/kg feed)	Treatments improved oxidative stability and increased total phenols of meats	Giannenas et al. (2018)
Medicinal herb extract mix (mulberry leaf, Japanese honeysuckle, and goldthread)	0.3 and 1% of basal diets	Treatments increased total phenols, DPPH-scavenging activity, and $ABTS^{+}$-reducing activity while lowering TBARS values during storage	Jang et al. (2008)
Pomegranate pomace extract	0.1, 0.2 and 0.3 g/kg feeds	At 0.2 and 0.3 g/kg, the additive increased DPPH-scavenging activity and decreased MDA concentration of broiler meats during the storage	Saleh et al. (2018)
Sumac (*Rhus coriaria*) fruit powder	2.5, 5.0 and 10 g/kg diets	At 5 g/kg, sumac fruit powder decreased TBARS concentration in thigh broiler meats	Saleh et al. (2018)
Blackcurrant (*Ribes*	1.25 and 2.5 g/kg	At 1.25 g/kg, the extract reduced	Sierzant et al.

nigrum L.) extract	feeds	MDA levels in frozen thigh meats	(2018)
Rosemary and blackcurrant extracts	2.5 and 5 g/kg feeds	The extracts reduced MDA concentration in frozen thigh meats	Sierzant et al. (2021)
Marigold extract	0.075, 0.15, 0.30 and 0.60% of diets	The extract increased total antioxidant capacity and the activity of SOD, while decreasing MDA contents of liver and thigh meats	Wang et al. (2017)
Mentha arvensis and *Geranium thunbergii* extracts	0.1% of drinking water	Treatment reduced TBARS and increased phenolic contents and DPPH activity of broiler meats	Yang et al. (2020)
Dried rosemary leaves and rosemary volatile oil	Rosemary leaves (5.7, 8.6, and 11.5 g/kg feed) and rosemary volatile oil (100, 150 and 200 mg/kg feeds)	Treatments lowered MDA levels of broiler meats	Yesilbag et al. (2011)
Nettle (*Urtica dioica*) powder	5 and 10 g/kg diet	Treatment did not affect TBARS levels in broiler meats	Keshavarz et al., 2014
Herbs extract mixture (Iranian green tea, cinnamon, garlic and chicory)	2.5, 5.0 and 7.5% of diets	The extract increased total phenols and decreased TBARS concentrations of broiler meats during storage	Shirzadegan and Falahpour (2014)
Cornelian cherry extract	50, 100, 200 and 400 mg/kg diets	The extract increased total phenolic content, DPPH, FRAP while lowering the MDA content of broiler meats during storage for 7 and 90 days	Ibrahim et al. (2021)

Consumers are interested in the increasing amount of n-3 long-chain PUFA in broiler meats because high levels of n-3 PUFA may boost human health benefits. However, compared to other fatty acid fractions and other chemical components in meats, n-3 PUFA is more vulnerable to lipid oxidation (Domínguez et al., 2019). There is a debate over the relationship between increased n-3 PUFA in broiler meats and lipid oxidation. As previously observed by Saleh et al. (2018) when pomegranate pomace extract was included in broiler feeds, dietary incorporation of herbal products might be one possibility to boost n-3 PUFA while preventing the oxidation process through the improvement of antioxidants in meats. However, further research is needed to corroborate this conclusion, as there is only a limited study that looks at the influence of dietary herbal supplementation on PUFA content and lipid oxidation in broiler meats at the same time.

CONCLUSIONS

Several factors affect the characteristics of broiler meats, one of which is stress conditions during the rearing period. The use of herbal or plant-derived products has been shown to lessen the negative impact of stress on broiler meats' physiological states and meat characteristics. The high content of phenolic compounds in herbs seems to improve oxidative stability and thus prevent the deterioration effect of nutrient oxidation on broiler meats during storage.

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