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Chapter

Use of Additives and Evaluation of the Quality of Broiler Meat

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Abstract

In the poultry industry, the demand for safe and quality meat in the market has increased considerably. The type of feed used and the management of poultry have a significant impact on the safety and quality characteristics of poultry meat. The use of additives that increase productivity and improve meat quality has generated much research. Nanoparticles, prebiotics, and probiotics have been used as growth promoters to increase and improve growth rate, performance, immunity, resistance to pathogens, as well as to improve meat quality. The type and level of these additives incorporated in the diets influence the animal's development and meat quality parameters. The aim of the study was to report the results of scientific research on the use of food additives used in broiler nutrition and their effect on meat quality.

Keywords: nanoparticles, prebiotics, probiotics, broilers, quality meat

1. Introduction

Broiler production is based on increasing meat quality, improving the characteristics of the chicken meat. Characteristics such as appearance, texture, juiciness, watery, firmness, tenderness, odor, and flavor of the meat are important for the consumer's judgment before and after purchasing a meat product. However, quantifiable meat properties, such as water-holding capacity (WHC), shear force, drip loss, cooking loss, pH, and shelf life, are indispensable for the processing of meat products with added value. Many research was carried out as an alternative to improve the quantity, quality, and homogeneity of farm animals and their products. The use of additives can contribute to improving animal performance and meat quality parameters. One of these alternatives is the supplementation of nanoparticles, probiotics, and prebiotics in the diet of broiler chickens.

In this review, general aspects of the use of nanoparticles, probiotics, and prebiotics in poultry feed are reported.

2. Nanoparticles

Nanomaterials are being used in agriculture, feed, and food [1]. Some are stable at high temperature and pressure [2] and can be easily assimilated into the digestive system [3]. The action mode of the nanoparticles depends mainly on many factors,

such as particle size, sizes smaller than 300 nm spread in the blood, but particles smaller than 100 nm reach tissues [4]. Thus, there is better interaction with other biologically active substances due to a larger surface area *in vivo* [5]. Other factors, such as the solubility of particles and fillers, are important. Nanoparticles can be administered by ingestion or inhalation and exercise their actions in different ways [6]. According to Gao and Matsui [7], nanoparticles have unprecedented properties, such as large specific surface area, high surface activity, many taut centers, and high catalytic efficiency. There are indications that nanoparticles and minerals can increase absorption [8].

Silver nanoparticles exhibit a strong antimicrobial effect [9]. On the other hand, the use of nano-minerals, such as nano-selenium, nano-chromium, or nano-zinc, can improve the parameters of animal production, their healthiness, and the quality of the products obtained from them, research has shown better effects in relation to the inorganic salts of these elements and chelates used on a large scale in the animal feed industry [10]. Considering this, in the livestock industry, research was conducted to improve the composition and quality of meat. Thus, the enrichment of feed with nanoparticles and their effects on meat properties were evaluated.

2.1 Growth performance

Selenium (Se) influences the physiological function and growth performance of animals and humans [11, 12]. Thus, it is necessary for various enzymes that are active in all cells. Dietary supplementation with selenium can increase growth performance in broilers [13, 14]. Studies show that the use of nano-selenium in supplementation improved weight gain and feed-conversion rate [15, 16], higher percentages of breast and drumstick, and a lower percentage of abdominal fat [15]. Some studies indicated that supplementation of 0.30 mg/kg of selenium improves growth performance [17–20]. According to Zhou and Wang [19] supplementation of diets with 0.30 mg/kg of nano-selenium with organic sources of selenium was effective in increasing growth performance and feed-conversion rates of broilers [16, 19]. Other studies showed no effect of nano-selenium supplementation in the diet in relation to body weight gain [21] and growth performance [22].

Zinc (Zn) is essential with widely variable functions in many important enzymatic processes of glucose, protein, and lipid metabolism and production and secretion of hormones [23]. It is nutritionally essential for the development and maintenance of growth performance in broilers [24]. The permitted level of Zn for poultry diets, as recommended by the National Research Council [25], is 40 mg/kg. However, high zinc content in the diet can lead to excess zinc in the feces, which causes environmental pollution [26], affects the balance of other trace elements in the body, and can reduce the stability of vitamins and other nutrients [27]. The substitution of the inorganic source of ZnO by nano-ZnO or combined nano-ZnO and Zn promoted the growth of broilers, increased the absorption of Zn and antioxidant status without negative influence on the distribution of selected minerals in broiler tissues [28]. Other studies have shown that nano-Zn supplementation improved weight gain and feed efficiency [29, 30], decreased cholesterol levels [31], decreased abdominal lipids [30] as well as improved the meat quality of broilers [30]. A concentration of 2.5 ppm of nano-ZnO can improve the performance of broilers [32]. Concentrations of 20 and 60 mg/kg of nano-ZnO can promote body weight gain [33].

Silver (Ag) has been considered antibacterial made by humans and can be used as an additive instead of antibiotics due to its antibacterial properties and adaptability

to biological systems [34]. Nanosilver was destructive in the influence on pathogenic intestinal microorganisms and induced better nutrient absorption, improvement in feed intake, weight gain, and feed efficiency of broilers [35]. However, the study conducted by Ahmadi [36] showed that when Ag-NPs were introduced in diets there was no improvement compared to control treatment, performance, body weight, feed intake, feed-conversion rate, and feed efficiency of broilers during a 42-day experimental period. This effect may be a result of Ag-NPs could affect organisms in the intestine (intestinal microflora). Nanosilver is an effective elimination agent against a broad spectrum of Gram-negative and Gram-positive bacteria [37], including antibiotic-resistant strains [38, 39].

Manganese (Mn) have an important role in bone development, normal nutrient metabolism, and biochemical processes, such as pyruvate carboxylase, superoxide dismutase, and glycolyltransferase [40, 41]. Levels of 100–400 mg/kg supplemental manganese sulfate (MnSO₄) decreased abdominal fat deposition [42, 43] and the level of malondialdehyde (MDA) in the broiler muscle, reducing lipoprotein lipase activity and increasing the activity of superoxide dismutase containing Mn (MnSOD) [42]. According to Brooks et al. [44] supplementation of Mn 20–500 mg/kg in diets for broilers did not affect BWG (weight gain) or FI (feed intake). Several other studies found no effects of dietary levels of Mn on growth performance [40, 42, 45–48].

Chromium (Cr) is important for physiological and nutritional activity [49]. It has potent hypocholesterolemic and antioxidant properties. It helps in the metabolism of fats, carbohydrates, and protein in animals; manifests itself in reducing the amount of glucose and cholesterol in the blood; helps in reducing fat deposits; and stimulates the formation of muscle tissue [50]. Kumari et al. [51] reported higher weight gain, the feed-conversion efficiency in the diet can produce lean meat with decreased muscle cholesterol and fat percentage for dietary supplementation with nano-Cr (400–1600 ppb). In the study conducted with chromium and nano-chromium supplementation and under thermal stress the results showed better performance, including weight gain and feed-conversion rate of broilers [52].

2.2 Meat quality parameter

The pH influences the quality of meat that reflects the change in acidity in the fermentation process of muscle tissue and speed of glycogen fermentation after slaughter, the stable pH value is conducive to normal maturation of muscles [53]. After slaughter, a rapid decrease in pH in the muscle results in the denaturation of the myofibrillar protein with the decrease in protein solubility, obtaining a poor WHC and greater drip loss [54], decreased juiciness, and intense muscle coloration [55].

The increase in the pH value observed after selenium supplementation indicates a delay in the metabolic conversion of glucose into lactic acid in the postmortem muscle [18]. The breast muscles of chickens that received nano-Se supplementation showed higher pH values after 45 min of 6.17 and after 24 h pH value 5.85 [18]. Similar results were reported for chicken breast meat with a Met-Se diet [56]. Mohammadi et al. [16] used dietary sources of Se and REO (rosemary essential oil) and did not observe effect at pH 4 h after slaughter.

Studies by Liu et al. [24] showed that Zn supplementation increases the pH value (5.88–6.06) after 24 h in the thigh muscle independent of the Zn source. A similar study was conducted by El-Hack et al. [30] who observed an increase in the pH value from 5.5 to 6.0 when supplemented with nano-ZnNPs. However, pH values of

6.15–6.25 were observed in chicken meat when supplemented to diet with nano-Zn (ZONPs - 10–50 ppm zinc oxide) [57]. Already lower pH values of 5.63–5.69 for chicken meat using nano-ZnO supplementation (2.5–40 ppm) were reported by Hussan et al. [32]. Supplemental Zn significantly increased pH values in broiler muscle [24, 57]. In agreement, Selim et al. [58] reported that chickens fed ZONPs reduced the pH of the breast muscle and thigh by 6.8%. ZONPs at 40 ppm reduced color and overall acceptability compared to control. According to Selim et al. [58], the use of ZONPs at 40 or 80 ppm did not affect the sensory evaluation of chicken meat, including texture, aroma, color, and general acceptability.

Shokri et al. [48] reported higher pH values for broilers fed diets supplemented with nano-Mn when compared with control, pH values 6.41–6.44 for breast and pH values of 6.50–6.83 for thigh after slaughter. After 4 h of slaughter, pH values of 6.15–6.24 for breast meat and thigh pH values of 5.99–6.20 were observed. Lu et al. [42] reported that the added Mn content had no effect on water-retention capacity and pH values in the thigh muscles and intramuscular fat in the chest and thigh muscles.

In a study conducted by Hashemi et al. [59], there were no differences in pH values after slaughter between control poultry and poultry fed nano-Ag, pH values from 5.38 to 5.78 for breast muscle were observed.

According to Sams and Mills [60], the normal pH values at the end of the post-mortem process are between 5.60–5.80 and 5.78–5.86, respectively. However, according to Soeparno [61], normal pH values would be in the range of 5.3–6.5. The high muscle pH makes the meat more susceptible to bacterial deterioration, while the low muscle pH increases the shelf life of chicken meat [62].

Some evidence indicates positive correlations between WHC and pH and a negative correlation between WHC and humidity [55]. In fact, Young et al. [63] explained that there is no good relative correlation between pH and water-retention capacity, and the lower overall final pH did not result in an overall decrease in water-retention capacity.

According to Huff-Lonergan and Lonergan [64], meat oxidation could decrease sensitivity to hydrolysis, weaken protein degradation, and reduce water reserves among myofibrils, which would increase meat juice loss by influencing softness and water-retention capacity.

Selenium is an essential trace element that positively regulates the antioxidant defense mechanism and is vital for the body's intra- and extracellular antioxidant systems [65]. Research shows improvement in antioxidant properties [18, 19, 65]. For levels from 0.15 to 0.3 ppm using different sources of if there was an improvement in oxidation levels [20].

MDA is one of the final products of the peroxidation of polyunsaturated fatty acids in cells and is a marker of oxidative stress [66]. Concentrations of 0.3–0.5 mg/kg of nano-Se in diet supplementation were effective to improve oxidation resistance by reporting lower MDA concentration in broiler samples fed diets supplemented with nano-Zn [18, 65]. The storage under cooling of the chest and thigh muscles is supplemented with Se observed a decrease in MDA concentration [16]. In addition, El-Deep et al. [17] reported a reduction in lipid peroxidation (MDA content) in broilers under high ambient temperature.

Changes in carcass characteristics may be due to increased tissue zinc residue, the effect of zinc on the antioxidant status and the oxidative enzyme, and especially the antioxidant function and water-holding capacity of muscle [24, 33, 58]. In the study by El-Hack et al. [30] the activity of liver enzymes and malondialdehyde (MDA)

decreased in the groups treated with nano-Zn (ZnNPs). Supplementation of broilers with 25 and 50 mg/kg of nano-Zn showed lower TBA values [67].

Hashemi et al. [59] observed an increase in MDA levels with an increase in nano-Ag supplementation levels. Protein oxidation can lead to the production of intermolecular bonds, including disulfide, dityrosine, and other intermolecular bridges to form the aggregation and polymerization of proteins [68].

Jankowski et al. [69] indicated that the antioxidant system worked properly when Mn was added in the form of nanoparticles, which can be attributed to the increase in the activity of Mn-SOD, GPx, and CAT. Lu et al. [70] reported that broilers fed diets supplemented with Mn presented low concentrations of MDA in the thigh muscle. Similar results were obtained when nano-Mn was added to the diets causing a reduction in the concentration of MDA in the thigh muscle in storage under refrigeration [48]. In contrast, Bozkurt et al. [71] reported that MDA concentrations increased in broilers fed diets supplemented with Mn. Already Bulbul et al. [72] reported that organic and inorganic sources of Zn and Mn decreased oxidative stress in laying hens.

According to Ognik et al. [73], a dose of 10 mg/kg in the form of NP-Mn₂O₃ induced large-scale lipid oxidation reactions. The reduction of Mn content, regardless of the form used, is disadvantageous, since it weakens the defense of the antioxidant system, which can induce oxidative processes in cells. In addition, the increase in dietary levels of Mn from 0 to 200 mg/kg in the diet regardless of the source showed lower values of TBARS [42, 43, 45, 70]. According to Kim et al. [43], high levels of Mn in the diet can be considered to improve carcass quality, preferably from the nano-Mn source because it presents higher bioavailability of Mn.

The oxidation of lipids in the breast muscle is a representative factor that reduces the quality of meat [74], and Mn is indicated as a necessary element for the production of SOD (superoxide dismutase) to increase antioxidant capacity and improve meat quality in chickens [41]. Oxidative changes in intramuscular lipids and products were determined based on TBARS [75, 76]. Thus, it has been demonstrated that the use of Mn in diets in organic (manganese methionine) or inorganic (MnO) forms increases MDA, glutathione peroxidase, and nitrogen oxide in chicken meat exposed to high-density stocking stress [71].

Studies report that Mn significantly reduced MDA levels in broilers [42, 70] and turkeys [77]. This may be due to the change in the activity of MnSOD (superoxide dismutase) in the mitochondria of muscle cells because MnSOD plays an important role in delayed lipid peroxidation of the cell membrane. However, there is an increase in the effect of MDA concentration with high Mn in the diet in the longissimus thoracis of pigs [78].

The activity of GSH-Px (glutathione peroxidase) affecting the oxidation state of myofibrillar protein could affect drip loss [79]. Studies report lower drip losses in breast meat of chickens who were fed nano-Se [19, 65] and organic Se [21, 80].

The pH drop retard leads to reduced protein denaturation, and consequently, to reduced drip and cooking loss [81], thus improving the water-retention capacity of meat. The use of nano-Se showed a decrease in drip loss [18].

Chicken meat with low pH has been associated with low WHC, which results in loss of cooking and drip loss. The lower pH decreases the ability of muscle proteins to bind to water, causing the shrinkage of myofibrils [82].

Some studies with nano-Se supplementation have observed an increase in meat water-retention capacity [83, 84]. In contrast, Mohammadi et al. [16] in the study reported that using dietary sources of Se and REO (rosemary essential oil) had no effect on water retention capacity (WHC) in the thigh and breast muscles in broiler.

Meat color and drip loss are important indices for assessing meat quality and are closely related to the oxidation state in muscles. The color of the meat is determined by the oxidation state of myoglobin [24]. The use of supplementation with it improves antioxidant capacity and thus could increase the content of myoglobin, thus improving the color of meat [83, 85]. In addition, when phospholipids in cell membranes are oxidized, changes in cellular permeability occur, leading to decreased water-retention capacity of the muscle.

Drip loss is commonly used as an indicator of the water-retention capacity (WHC) of meat. The lower drip loss reflected the higher content of water-soluble nutrients and the increase in meat juiciness [86]. Lower drip losses of the breast muscle were observed when supplemented with nano-Zn (ZONPs 25–50 mg/kg ZnO) [57]. On the other hand, Liu et al. [24] and Selim et al. [58] reported that additional nano ZONPs decreased drip loss in broilers. Similarly, Saenmahayak et al. [87] reported that drip loss increased significantly in the muscles of broilers fed zinc supplemented diets.

The decrease in drip loss in the breast muscle [78] can be attributed to a stable pH value [88].

Regarding water-retention capacity (WHC) no difference was observed in supplementation with nano-Zn [32, 87]. In contrast to our results, Yang et al. [89] recorded an increase in breast muscle WHC with the addition of inorganic zinc in broilers.

The physical and chemical properties of proteins, including solubility, hydrophobicity, WHC, and even nutritional value can be modified by protein oxidation [90]. In postmortem muscle, protein oxidation has been gradually recognized as an important factor for meat quality. During postmortem storage, the muscle has a decreased ability to maintain its antioxidant defense system, and this can cause an increased accumulation of reactive oxygen and nitrogen species [91]. Improved antioxidant status can promote the maintenance of cell membrane integrity [65], which can be explained by the results of water-retention capacity. According to Hashemi et al. [59], there was no significant difference for breast in WHC value, while thigh supplementation with nano-Ag resulted in higher levels of WHC, which may be due to the low level of protein oxidation.

The quantifiable properties of meat are indispensable for processors involved in the manufacture of meat products, such as water-retention capacity (WHC), shear force, drip loss, cooking loss, pH, shelf life, protein solubility, and fat-binding capacity [92].

Muscle pH had a significant positive correlation with water-retention capacity (WHC), and WHC had a significant correlation with an a^* value [55].

In addition, thighs with nano ZnNPs lower loss by cooking [67].

The color of meat is an indicator of quality, which represents its freshness for consumers [93]. Some studies did not report differences in the color of the breast muscles for supplementation with nano-Se compared to the control [18, 56, 83]. Meanwhile, Boiago et al. [94] observed a decrease in L^* values of breast muscles for broilers fed diets supplemented with Met-Se Se, which may be related to a reduction in moisture on the meat surface because of increased water-retention capacity [95].

El-Hack et al. [30] reported lower L^* values for breast meat from chickens treated with dietary supplements of nano-Zn ZnNPs and did not observe differences for a^* values. For thigh meat, the different treatment groups with nano ZnNPs did not affect the values of L^* and a^* [67]. However, for the value of b^* there was an increase for the thigh muscle [24, 67] and the breast muscle [24, 30, 89].

According to Hashemi et al. [59] in the treatments of zeolite, nano-silver (50 and 75 ppm) there was no significant difference for the color parameters parameter L^* , a^* , and b^* in the breast muscle.

Lipid oxidation can promote the accumulation of metmyoglobin, such as brown pigments, in meat [94, 96]. The increase in the yellowing of meat may be due to the increase in the formation of oxymyoglobin [97]. In addition, lipid oxidation is associated with the destruction of meat pigments, such as carotenoids [98]. Some researchers have also demonstrated that there is a significant negative correlation between the color values of clarity of breast meat and the pH of breast meat [62]. Color is the most important characteristic for the appearance of meat [99], which is influenced by sex, genotype, and breed; moreover, it relates to the pH value [100].

Softness, described as shear force, is an important indicator of consumer acceptability and is determined by the structural properties of various proteins and fats in muscle [101]. Nano-Se supplementation showed a decrease in the value of the shear force of the breast muscles and lower cooking loss [18].

Baowei et al. [85] reported that SS supplementation in the 0.3 g/kg diet reduced the hardness of the goose's breast muscles. Results indicate that the supplementation of broiler feed with organic Se or nano-Se leads to improvement of meat quality, in relation to the addition of inorganic Se [102].

Many studies have shown that IMP (inosine 5'-monophosphate) contributes to the sensory perception of meat [101]. A higher IMP content was observed in chickens supplemented with nano-Se may be associated with a better quality of Guangxi Yellow chicken meat [19].

Zn supplementation increased the content of intramuscular breast muscle fat in broilers independent of the source of Zn [24]. Hodgson et al. [103] observed that higher levels of intramuscular fat caused a significant decrease in shear force. Liu et al. [24] showed that Zn supplementation decreased the shear force of the thigh muscle and breast muscles, regardless of the source of Zn.

Texture parameters such as succulence, softness, and flavor obtained lower values when using a diet with nano ZnNPs [30].

Regarding the texture profile of broiler breast meat for hardness, cohesiveness, gumminess, and chewiness were influenced by the treatment with nano Ag (NZ75 higher values), while adhesiveness and springiness were not influenced [59]. For the thigh muscle texture profile of broilers, hardness, adhesiveness, and cohesiveness were not influenced, however there was a difference in springiness for supplementation with nano Ag [59]. Results may be related to water-retention capacity (WHC), a quality parameter related to the meat softness process, which is an important parameter in the sensory evaluation of meat [104].

Yang et al. [77] reported the use of Mn in the duck diet, they observed a significant increase in intramuscular fat and decreased shear strength, showing similar results in studies conducted by Yang et al. [89] in broilers.

Meat softness is a factor used to evaluate the acceptability of the consumer of cooked meat [99] and is generally associated with the content of MIF and muscle fiber structure [105]. Shear force is a reliable indicator that inversely represents the softness of the meat.

3. Probiotic, prebiotic, and simbiotic

Probiotics are considered live microbial supplements that beneficially influence the host by improving intestinal microbial balance [106], stimulating metabolism, reducing the risk of infection by opportunistic pathogens [107], tend to improve levels of body antioxidants, which can improve the health of broilers [108]. The

study has shown that dietary probiotic supplementation increases growth rate, feed efficiency, and immunity in chickens [109], improve chicken meat quality, such as WHC, tenderness, and oxidative stability [110], increase weight gain and feed-conversion ratio, improve antioxidant capacity in organs and muscle tissue in heat-stressed chickens [111]. Probiotics used in animal nutrition include groups of bacteria, yeasts, and fungi, such as *Lactobacillus acidophilus*, *L. lactis*, *L. plantarum*, *L. bulgaricus*, *Lactobacillus casei*, *L. helveticus*, *Lactobacillus salivarius*, *Bifido bacterium* spp., *Saccharomyces cerevisiae*, and *S. boulardii* [112–114].

The prebiotic is a nondigestible feed ingredient that, through its metabolization by microorganisms in the gut, modulates the composition and/or activity of the gut microbiota, thus conferring a beneficial physiological effect on the host [115]. The prebiotics are used as substrates for survival and multiplication of probiotics in a lower gut region that act as symbiotics [116]. Some prebiotics are composed of diverse sugar units. Therefore, each prebiotic may influence the animals differently [117]. Prebiotics such as fructooligosaccharides (FOS), galactooligosaccharides (GOS), and mannan oligosaccharides (MOS) are considered preventive agents, as they can select a gastrointestinal microbiota that not only benefits the host but can serve as a barrier to the colonization of pathogens [118]. Besides, feed additives, such as probiotics, prebiotics, and symbiotics have been proposed as a nutritional strategy to improve the resilience of animals against heat stress [119].

3.1 Growth performance

Probiotics have a beneficial effect on the host animal, improving its intestinal microbial balance [120]. This creates a healthy intestinal environment with increasing counts of healthy bacteria and suppresses intestinal pathogens, thereby improving digestion and nutrient utilization [121]. According to Al-Shawi et al. [122], the animal not only requires an optimal amount of food but also must improve the digestibility of the food to maximize growth. Some studies have reported lower feed intake in broilers fed with probiotics [123–126]. Thus, increased nutrient absorption in broilers produces lower feed intake to maintain their nutrition needs [127]. Amerah et al. [123] reported that the inclusion of *B. subtilis* in the feed improved the feed-conversion ratio by reducing feed intake.

The inclusion of *Bacillus* species as a dietary supplement increased performance [126, 128] and reduced mortality [126, 129]. A similar result has been reported when using *S. cerevisiae* as a supplement [124]. Probiotics can improve the performance of chickens by improving the immune response [130]. However, Amerah et al. [123] found no beneficial effect on body weight gain (BWG) in broilers with the inclusion of *B. subtilis* in the diet. Other studies have reported no effect or minimal effect of probiotics on the growth performance of broilers [131, 132].

Bai et al. [133] evaluated the feeding of broilers with *B. subtilis* in the diet and reported higher average daily gain (ADG) and lower feed-conversion ratio (FCR). On the other hand, broilers with the inclusion of *S. cerevisiae* in the diet improved the weight gain and the feed-conversion ratio (FCR) [125, 134–136]. Studies have shown that feeding with a dose >1.0% of *S. cerevisiae* diets produces higher body weight, low feed-conversion ratio compared to chickens fed a low dose of yeast [125, 137]. In contrast, in other studies, body weight gain and feed-conversion ratio (FCR) were not influenced by supplementation with yeast in the basal diet [138–140].

According to Patel et al. [141], the effectiveness of probiotics is influenced by the selection of the most efficient strains, manipulation of genes, combination of several

strains and the combination of probiotics, and synergistically by the action of the components. However, the use of multiple strains may improve the effectiveness of probiotics as they beneficially affect the host by enhancing growth-promoting bacteria with competitive antagonism against pathogenic bacteria in the gastrointestinal tract [142].

In the broilers fed with multi-strain probiotics, such as *L. acidophilus*, *B. subtilis*, *S. cerevisiae*, *Enterococcus faecium* [113], *A. oryzae* [124], *L. casei*, *Bifidobacterium thermophilum*, *Enterococcus faecium* [121], and *Clostridium butyricum* [114], body weight gain, better feed-conversion rate (FCR) [113, 121, 124], and a lower percentage of abdominal fat was observed [124]. In quail, the highest final body weight (BW) values were recorded in groups T5 (probiotic bacteria—*B. toyonensis*) and T10 (probiotic bacteria—*B. toyonensis* and *Bifidobacterium bifidum*). Thus, in the termination period, the use of a higher level of probiotics (T5) reported an increase in body weight gain (WG) [143].

Therefore, the effectiveness of the application of probiotics varies depending on several factors, such as probiotic strains, dosage of administration, method of administration, diet composition, age and breed of birds, and management conditions [114, 131, 132, 136, 144].

The positive prebiotic effect on growth performance can be due to the ability of prebiotics to enhance lactobacilli and bifidobacteria populations, and these beneficial bacteria compete with harmful bacteria for colonization [145].

Prebiotic diet reported higher carcass weight, carcass yield, and breast muscle weight [146, 147], and an increase in body weight gain [148].

The study observed a significant effect of diet on feed conversion, and control birds showed poor feed conversion. The rearing system also affected weight gain and feed intake, so confined birds had better weight gain and feed intake [149]. Birds fed diets supplemented with probiotics and prebiotics showed greater body weight and weight gain, whereas feed intake was greater in control birds. Similar studies, diets with prebiotic treatment and probiotic alone, reported better responses for body weight gain and FCR compared to the use of symbiotic treatment [150]. Several other studies also showed that the addition of probiotics or prebiotics alone or in combinations as synbiotics in feeds had no effect on the feed intake of broiler chickens [151]. On the other hand, dietary synbiotic supplementation can increase the breast muscle weight of broilers in comparison with those fed the basal diet [152].

3.2 Meat quality

The physicochemical properties of meat are important and can determine its storage or further processing. They are interconnected and influence the sensory quality of meat. Thus, the use of probiotics can influence these parameters [153]. Meat quality is also a very important parameter for the effect of dietary treatment in broiler studies. The supplementation of probiotics in basal diets had beneficial effects on quality broiler meat [128, 133].

The decreased pH relates to the generation of lactic acid through the anaerobic pathway, and probably promotes the denaturation of myofibrillar proteins, and reduces the ability of these proteins to maintain water [154]. Wang et al. [155] observed the decline in pH, however, pH_{24h} (6.01) was increased by *S. cerevisiae* supplementation in relation with the control (5.80). Similar results have reported the inclusion in the diet of *S. cerevisiae* [156] and mixture *Pediococcus acidilactici* and *S. cerevisiae* [157]. Other studies showed that yeast products or culture improved the

meat quality of broilers and pigs by decreasing the yellowness and stabilizing the pH of meat [102, 158, 159]. However, the study of fresh quail meat observed an increased pH value with the probiotic treatment in the diet of groups T4 (*B. toyonensis*-BT) for T6 (*B. bifidum*; 6.71–6.83) and decreased for T2 (lowest level of BT, pH 6.02) in comparison with the control (6.31) and the remaining groups (6.33–6.43) [143].

On the other hand, Cramer et al. [160] observed that *B. subtilis* supplementation and heat stress did not influence the extent of pH decline up to 4 h postmortem, so the pH of breast muscles from control or probiotic slightly decreased. Yet, the probiotic mixture (*E. faecium*, *P. acidilactici*, *Bifidobacterium animalis*, and *Lactobacillus reuteri*) feeding levels and cyclic heat exposure for 6 h postmortem did not influence the extent of pH decline up to, so the pH of breast muscles from control or probiotic slightly decreased [161]. Similarly, the study reported that heat stress does not affect the initial temperature decline (from 15 min to 24 h postmortem) of breast muscles at commercial slaughter conditions [162]. Cramer et al. [160] observed a significant interaction on ultimate pH at 24 h postmortem, increased ultimate pH values 5.90 and 5.95 by thermoneutral and heat stress, respectively, of broiler breast (*B. subtilis* supplementation). Similar results were observed by Aksit et al. [163], Zhang et al. [144], and Kim et al. [161]. Heat stress can lower the initial and final pH of chicken breast muscles, heat stress normally increased lactate accumulation and the rate of postmortem glycolysis due to the high activity of glycolytic enzymes, such as pyruvate kinase and lactic dehydrogenase [144, 164]. According to Cramer et al. [160], probiotic supplementation could alleviate the pH decline of breast muscles from heat-stressed broiler by likely affecting the rate of postmortem glycolysis metabolism. Some studies reported that microbial probiotic supplementation could increase the ultimate pH of broiler breast muscle [156, 165, 166]. Already Aksu et al. [156] observed an increase in pH values 6.24–6.31 of chicken breast muscle when used 0.2% *S. cerevisiae* in the diet. In another study, Zheng et al. [166] included *E. faecium* supplement in feed chickens and found that breast muscle had a higher ultimate pH value (6.11) than that from control (5.77). Hence, the high ultimate pH of breast muscle might be related to the downregulating effect of probiotic supplementation on glycolytic enzymes that could alleviate an increase in glycolytic metabolism induced by high ambient temperature [161, 166]. Nonetheless, some studies have reported no effect on pH values on broiler breast meat when using *B. subtilis* (6.67–7.03) [133] and *S. cerevisiae* (5.6–6.16) [167].

In cooking loss in broiler no difference was reported, regardless of probiotic feeding levels [165, 168, 169]. Also, the drip, cooking, and thaw losses on breast muscle were not observed by Benamirouche et al. [157]. However, some studies observed that heat stress increases drip and cooking loss [79, 144] of the breast meat [167]. In contrast, lower cooking loss was observed in *S. cerevisiae* supplement diet [155], and lower drip and cooking losses of broiler breast muscles were observed when using the probiotic in broiler [133, 160]. An increase in drip loss in broiler muscle under heat stress has been attributed to protein denaturation or loss of protein functions due to a rapid decline in pH when carcass temperature is high [144, 164]. Broilers fed probiotic supplement diet showed higher breast meat WHC than broilers fed without probiotic [165, 167, 170]. A similar result was observed in quail meat [143]. In meat quality, water-holding capacity, including drip loss and cooking loss, are crucial because some nutrients could easily lose during exudation by water loss [171]. Zhang et al. [144] suggest that the decreased final pH could be associated with the poor quality characteristic of breast muscle from heat-stressed broilers, especially on color, WHC, and tenderness.

Meat tenderness can be estimated by measuring the shear force; lower shear force indicates tenderer meat and was one of the crucial sensory qualities that influenced the consumer [172]. The shear force in breast and drumstick meats decreased with *S. cerevisiae* treatments [144] and *B. coagulans* in breast meat [128]. Suggests that the dietary supplementation of *S. cerevisiae* could improve meat tenderness of broilers [128, 135, 165, 173, 174]. However, in other studies, no beneficial effects were observed [144, 175]. Heat stress and feeding broilers with probiotics no influence the shear force of the broiler breast muscles [160]. Greater tenacity was reported by Zhang et al. [144] in treatment with heat stress, while Lu et al. [176] found heat stress had no effect on the shear force of chicken breast meat. In addition, these findings indicate that probiotic mixture supplementation observed no influence on WHC and shear force of breast muscle from chickens exposed to cyclic heat [161]. The pH and water-holding capacity of the meat are important quality attributes; high pH broiler breast meat has higher water-retention capacity than lower pH meat, resulting in increased tenderness [177].

No interactions between probiotic feeding levels and display storage time on CIE L* (lightness), CIE a* (redness) breast muscles from chickens exposed to cyclic heat challenge were found, except for CIE b* (yellowness) [160, 161]. The quail meat color a*, b*, and L* values were decreased by probiotics treatment with all levels studied as compared to the control group [143]. Haščík et al. [178] observed an increase in a* and b* values of the thigh and an increase in the L* values of breast and thigh cuts in birds fed probiotics alone or in combination with pollen. In contrast, Haščík et al. [179] reported that a* values in breast muscle were increased, whereas the values of L* and b* for broiler breast meat were not altered because of *Lactobacillus fermentum* supplementation. The L* values change has been previously correlated with low ultimate pH and poor WHC [55].

The MDA concentration shows the intensity of the lipid peroxidation rate in the body and indirectly shows the degree of damage by tissue peroxidation [155]. Some studies have reported an antioxidant effect of probiotic feeding on lipid oxidation, suggesting that the improved meat quality might be closely connected with its enhanced antioxidant capacity by yeast supplementation in broilers [110, 133, 135, 155, 156, 160, 169, 170, 180]. Thus, it can improve the quality parameters of broiler meat under heat stress. However, in a study by Kim et al. [161] no effects on lipid oxidation stability were observed.

Sensory evaluation test results for lightly cooked breast meat, there was an improvement in the odor of chicken meat fed with *S. cerevisiae* supplement. Other sensory attributes show no influence between treatments [167]. According to the previous studies, there was widespread agreement about sensory quality and intramuscular lipid content [181]. Apart from that, the result of Nakano [182] suggested that the fat in the meat was converted into the favorable fat in the presence of probiotics for preferable sensory qualities. In addition, supplementing probiotics in basal diets had beneficial effects on the meat quality of broilers [128, 133].

Broiler chickens subjected to heat stress can induce a lower final pH with variation in meat color, water-holding capacity (WHC), and meat tenderness [81, 144, 163], resulting in lower acceptability of the meat by the consumer. In this sense, poultry farming strives to mitigate the negative effects of heat stress on poultry production, to reduce economic losses. The main concerns about the use of these bioactives are their efficient administration under fully controlled conditions.

Heat stress not only impairs muscle growth and structure [160, 183], but also influences meat quality, decreasing the pH value, water-retention capacity and redness, and increasing skeletal muscle lightness in chickens [5, 184–186].

Some studies suggest that the glucose level in skeletal muscles may be influenced by heat stress, causing an accumulation of lactic acid in muscle tissue [144], and a rapid decline in pH with low pH values final [5, 144, 160]. Tavaniello et al. [147] and Maiorano et al. [187] no reported influenced pH 24 (5.76 and 5.87) fully fit within the pH range accepted for commercial poultry meat [178, 179]. Already lower values of pH 24 h postmortem were observed under heat stress conditions with and without the use of symbiotic compared to the control.

The redness a^* value was reduced in breast meat from prebiotics treatment compared to control [147]. Yet, L^* and b^* values were similar between the experimental groups. Dietary symbiotic addition reduced L^* value. However, it did not affect the b^* value [152]. The a^* values were lower for the thermoneutral symbiotic, but higher a^* values were reported for heat stress and symbiotic. Other studies reported that heat stress can increase L^* and reduce a^* and b^* of breast meat [119]. This could be due to the denaturation of sarcoplasmic proteins, which results in the scattering of light [144].

Less drip and cooking losses were observed, and there was no effect on breast muscle shear force in broilers fed symbiotic compared to those fed a basal diet [152]. However, sob heat stress increased drip loss and cooking loss and decreased shear force in broilers when compared with those under thermoneutral temperature [152]. Similar results were found in broiler exposed to heat stress, which observed decrease in the WHC [119].

Broilers exposed to heat stress reported higher MDA concentration but lower activities of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) in the breast muscle. Compared with broilers fed the basal diet, symbiotic supplementation decreased MDA content and increased GSH-Px activity of breast muscle in broilers [152].

4. Conclusions

Meat quality is influenced by several factors, such as food. The use of additives to improve meat characteristics was evaluated. It was shown that the type of additive, the quantity, and the method of application are important parameters for obtaining chicken meat with desirable characteristics for the consumer and for the industry in obtaining meat-derived products.

Conflict of interest

The authors declare no conflict of interest.

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