2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 2: 107-115; March 25, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.13

CHITOSAN OLIGOSACCHARIDES AS DIETARY ANTIOXIDANTS IN NUTRITION OF BROILER CHICKENS: A REVIEW

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Supporting Information

REVIEW ARTICLE
PII: S222877012400013-14
Received: October 18, 2023
Revised: February 09, 2024
Accepted: February 15, 2024

ABSTRACT: Chitosan oligosaccharides (COS) have attracted considerable attention in poultry research due to their diverse biological activities and possible effects on the welfare and productivity of broiler chickens. A thorough examination of many studies indicates that the influence of COS on indices such as antioxidative functions, growth performance, immunological responses, and metabolic implications in broilers is significant. For example, specific dosage levels of COS have significantly enhanced antioxidant activity, regulation of cholesterol levels, and improved growth performance. The research findings have provided evidence for COS's antioxidative and anti-inflammatory properties and its capacity to mitigate the effects caused by stress. Nevertheless, the effectiveness of reactions might be influenced by the dosage and may demonstrate variances. Broiler chickens are suggested to consume dietary COS levels between 350 mg/kg and 500 mg/kg feed to obtain antioxidant and immunological advantages. Nevertheless, the most favourable results regarding growth and the ability to absorb nutrients are typically found when the intake ranges from 0.5 g/kg to 1.0 g/kg feed. For yellow-feather broilers experiencing heat stress, it is advisable to administer a dosage of 200 mg/kg feed of COS. However, it is essential to closely observe dosages exceeding 2.5 g/kg since they may significantly impair growth performance. The diverse research on using COS in broiler management has provided valuable insights into its intricate nature. This review has highlighted the potential benefits of COS in enhancing chicken health and nutrition. However, it has also underscored the need for additional research to optimize its effectiveness entirely in broiler performance. It can be concluded that dietary COS in broiler chickens in doses ranging from 200 mg to 1000 mg/kg feed has a positive effect on growth performance, antioxidative properties, regulation of lipid metabolism, ability to mitigate stress, impact on meat quality, and carcass traits, but exceeding 2.5 g/kg feed may significantly impair in growth performance in the broiler chickens strain Cobb 500.

Keywords: Antioxidative, Anti-inflammatory, Broiler, Chitosan oligosaccharides, Growth Performance, Meat Quality.

INTRODUCTION

The production of broiler chickens is crucial in providing the worldwide need for protein of superior quality. Consequently, ensuring broiler chickens' well-being and efficiency is essential for the poultry sector. Nevertheless, broiler chickens frequently face many environmental stresses, such as exposure to low or high temperatures, potentially impacting their overall welfare and efficiency (Quinteiro-Filho et al., 2010). Throughout the context of physiological problems, two significant concerns that occur are oxidative stress and inflammation.

The occurrence of oxidative stress in broiler chickens is characterized by an imbalance between the release of reactive oxygen species (ROS) and the ability of the antioxidant defence system to neutralize them (Surai et al., 2019). This condition can lead to cellular harm, hindered growth, and diminished general well-being in these broiler chickens. Simultaneously, inflammation, though a protective response, can become detrimental when chronic, damaging tissue and compromising the immune system. Furthermore, enhancing the antioxidative functions, growth performance, immunological responses, and metabolic consequences are paramount due to their direct impact on poultry health and production efficacy.

Chitosan oligosaccharides (COS) are a natural polymer derived from chitin's deacetylation process (Lodhi et al., 2014). These chitosan oligosaccharides possess distinctive biochemical characteristics and exhibit minimal toxicity, making them a promising candidate for revolutionizing as feed additives (Elnesr et al., 2022; Uyanga et al., 2023). Recently, there has been a growing interest in using natural feed additives within the poultry sector, particularly in broiler performance. The research areas encompass antioxidative functions, growth performance, carcass characteristics

Citation: Harahap RP, Sholikin MM, Sadarman (2024). Chitosan oligosaccharides as dietary antioxidants in nutrition of broiler chickens. *Online J. Anim. Feed Res.*, 14(2): 107-115. DOI: https://dx.doi.org/10.51227/ojafr.2024.14

response, anti-inflammatory activities, and effects on lipid metabolisms. Although significant insights have been gained from this research, a comprehensive comprehension of the role and consequences of chitosan oligosaccharides in broiler performance remains necessary. The objective of this study is to critically examine the existing studies to establish a comprehensive comprehension of the present state of research on this particular topic. Additionally, it intends to emphasize the areas that require future exploration to exploit the advantages of COS effectively. This evaluation provides a foundation for further exploration and potential adoption within the poultry industry. This review examined the diverse ramifications of chitosan oligosaccharides, encompassing their growth performance, antioxidative characteristics, control of lipid metabolism, stress mitigation capabilities, and influence on meat quality and carcass attributes.

Physical, chemical, and biological properties of chitosan oligosaccharides

Chitosan oligosaccharides (COS) are derived by deacetylation and depolymerization of chitin or chitosan, employing physical, chemical, or enzymatic techniques (Benchamas et al., 2021). Chitin is predominantly derived from the exoskeletons of crustaceans, such as shrimp and crabs, as well as the fungus cell walls. It is the second most abundant natural biopolymer, surpassed only by cellulose. Chitosan oligosaccharide comprises D-glucosamine and N-acetyl-D-glucosamine units connected by β-(1→4)-glycosidic linkages. Low molecular weight variants of chitosan possess a reduced molecular size and exhibit solubility in water, augmenting their bioavailability and efficacy in diverse applications (Naveed et al., 2019).

Chitosan oligosaccharides (COS) exhibit noteworthy biological characteristics, including antibacterial, antioxidant, anti-inflammatory, and antihypertensive capabilities (Guan et al., 2019). According to Lizardi-Mendoza et al. (2016), one of the pivotal attributes of COS is its biodegradability, positioning it as an environmentally friendly material by allowing it to decompose naturally, reducing concerns related to environmental accumulation and pollution. In addition to its eco-friendly nature, COS is recognized for its biocompatibility, implying that it is non-toxic to living cells, thus paving the way for its utilization in a spectrum of biomedical applications where cellular and tissue compatibility is paramount (Razi, 2022). This non-toxicity also extends its safe use to various other applications, ensuring that it does not threaten health or the environment (Lizardi-Mendoza et al., 2016). The water-soluble nature of COS enhances its bioavailability, facilitating its interaction and functionality in various applications, particularly in aqueous systems, which is often a prerequisite in industrial and biological applications.

Furthermore, the structural properties of chitosan oligosaccharides (COS) are noteworthy, as they cater to specific requirements across food, pharmaceutical, and biomedical sectors, providing stability, form, and function that can be tailored to meet the specific demands of various applications (Razi, 2022). The modified biomaterial exhibits a higher degree of deacetylation (DD), degree of polymerization (DP), reduced viscosity, and complete solubility in water, distinguishing it from its precursor biomaterials and other polysaccharides currently available (Naveed et al., 2019). The hydrophilic nature of this biopolymer has been skillfully harnessed in combination with other chemicals to effectively modify their surface structures, resulting in the creation of chemically appropriate surfaces (Prihandini et al., 2021). The degree of deacetylation of COS is usually less than approximately 50%, and their average molar mass is less than 10,000 Da. These properties contribute to their solubility in water and result in low-viscosity solutions (Shukla et al., 2015). According to the research conducted by Shukla et al. (2015), applying a COS coating on iron oxide nanoparticles reduces cellular damage and a modest generation of reactive oxygen species (ROS). Consequently, this coating effectively mitigates the cytotoxic effects of uncoated iron oxide nanoparticles.

Recent study of dietary chitosan oligosaccharides in broiler

The considerable influence of chitosan oligosaccharides (COS) in the diet of broiler chickens, as evidenced by various research, presents a persuasive account of its potential utility in improving the well-being and efficiency of poultry. The present study, as outlined in Table 1, comprehensively examines multiple investigations examining dietary COS effects on broilers. Each study has contributed valuable insights into different aspects and results associated with dietary COS in broilers. These studies, conducted over a range of years and with different study goals, investigate the effects of varying dietary COS on parameters such as antioxidative functions, growth performance, immunological responses, and metabolic consequences, among other factors. For example, the research conducted by Xiaocong et al. (2017) and Keser et al. (2012) investigates the antioxidative and biochemical profiles, uncovering significant results such as improved antioxidant activity and regulated cholesterol levels, respectively. Several research studies have also examined the intricate effects of COS on growth performance, with specific dose levels demonstrating the most favourable outcomes, as demonstrated by Osho and Adeola (2019) and Tufan and Arslan (2020).

Furthermore, the investigation into the antioxidative and anti-inflammatory effects, together with the ability to alleviate stress-induced effects, as demonstrated in the research conducted by Lan et al. (2023) and Fathi et al. (2023), presents a positive perspective on the function of chitosan oligosaccharides (COS) in the field of poultry nutrition and health. The various studies conducted on COS in broiler management highlight its complex character and provide a foundation for further investigation. It calls for a thorough examination to enhance our understanding and maximize the effectiveness of COS in broiler performance.

Table 1 - Summary of some reported studies on dietary chitosan oligosaccharides in broilers and its outcomes.

Level of COS	Parameters	Outcomes	Reference
0.025%	Performance and biochemical profiles in broiler such as serum levels of total cholesterol, HDL-cholesterol, LDL-cholesterol, VLDL-cholesterol, triglycerides, free fatty acids, total protein, urea, insulin, glucose, glutamic oxaloacetic transaminase (GOT), and glutamic pyruvic transaminase (GPT)	There were no significant effects of COS on the performance of broilers. It did result in significant reduction in LDL-cholesterol levels.	(Keser et al., 2012)
0, 200, 350 and 500 mg/kg feed	Antioxidative function, lymphocyte cycle and apoptosis of ileum mucosa in broiler	Dietary COS with 350 mg/kg and 500 mg/kg could improve the antioxidant function and accelerate lymphocyte proliferation but had no influence on lymphocyte apoptosis in the ileum mucosa of broilers.	(Xiaocong et al., 2017)
0, 0.5, 1.0, 1.5, 2.0 and 2.5 g of COS/kg feed	Growth performance, digestive functions, intestinal morphology, and immune organ	Level COS (between 0.5 g/kg and 1.0 g/kg) might be optimal for positive growth effects, immune responses and nutrient digestibility. However, they have also mentioned that growth performance showed signs of impairment at a higher level of 2.5 g/kg COS in the diet.	(Osho and Adeola, 2019)
0, 1 g/kg feed	Growth performance, nutrient digestibility, jejunal morphology, gene expression, and plasma antioxidant enzyme	Dietary COS at 1 g/kg can mitigate stress and improve growth performance and immune function in broiler chickens, especially under dexamethasone (DEX-induced) stress conditions.	(Osho and Adeola, 2020)
0, 200 mg/kg feed	Growth performance, corticosterone, growth hormone, and insulin-like growth factor-1 concentration, relative organ weight, liver function, meat quality, muscle glycolytic metabolism and oxidative status	Dietary COS can be an effective feed additive for maintaining growth performance, liver function, meat quality, muscle glycolysis metabolism, and oxidative status in yellow-feather broilers under heat-stress conditions. Dietary COS could also alleviate heat stress, as evidenced by the improved growth performance and reduced heat stress markers in broilers.	(Chang et al., 2020)
0, 100, and 200 mg/kg feed	Oxidative stress and inflammation response in liver and spleen	Dietary COS at 200 mg/kg of diet significantly alleviated oxidative stress and inflammation response in yellow-feather broilers exposed to high ambient temperature. Specifically, the inclusion of 200 mg/kg COS led to a decrease in Malondialdehyde content, which suggests reduced oxidative stress, increased activities of antioxidant enzymes Superoxide Dismutase and Glutathione Peroxidase, and increased level of the anti-inflammatory cytokine Interleukin-10 in vital organs. The 100 mg/kg COS also showed improvements, but these were more significant at the 200 mg/kg level.	(Lan et al., 2020)
0, 50, and 100 ppm of COS	Growth performance, blood parameters, carcass traits, fatty acid composition of breast meat, and apparent nutrient digestibility in broiler chicken	Diets added with 50 ppm COS showed a higher average live weight gain, decreased feed intake, and improved carcass yield (higher dressing percentage and increased breast and leg weight) compared to the control group. They also experienced lower total cholesterol, low-density lipoproteins, very low-density lipoproteins, and triglycerides. The 100 ppm COS group also improved but was less marked than the 50 ppm COS group. Therefore, the 50 ppm dietary COS seemed more effective in this study. However, it did not significantly affect key growth performance parameters such as live weight, average weight gain, and feed conversion.	(Tufan and Arslan, 2020)
0, 262, 350, 437 g/ton feed	Growth performance, gut morphology, and serum biochemistry	The serum glucose level was significantly lowered in the 350g/ton and 437g/ton COS groups compared to the control group, which could indicate improved health. The serum concentrations of total protein, albumin, and globulin were gradually increased in all treatment groups, along with the increase in COS dose rates compared to the control group. The 437g/ton COS group had the highest total protein value. The aspartate aminotransferase (AST) liver enzyme level increased with the dose rate, particularly in the 437g/ton COS group.	(Ayman et al., 2022)
0, 400 mg/kg feed	Rectal and surface temperature, oxidative status, the expression of mapk-nrf2-are signaling pathway-related genes, and meat quality	Dietary 400 mg/kg COS and were exposed to acute heat stress (the AHS-C group). Decreased reactive oxygen species and malondialdehyde content compared to the acute heat stress (AHS group). Increased breast muscle pH both at 45 minutes and 24 hours postmortem in comparison to the AHS group. Improved redness of the meat, cooking loss, and shear force compared to the AHS group. Increased catalase activity compared to both the AHS and control groups.	(Chang et al., 2022)

0, 600 mg/kg feed	Hepatic antioxidant capacity, inflammatory response, and lipid metabolism in heat-stressed broilers. In addition, they used body weight, liver weight, abdominal adipose weight, average daily feed intake, average daily gain, and feed conversion ratio as parameters for evaluating the effects of COS on broilers under heat stress conditions	Dietary COS 600 mg/kg feed had beneficial effects on heat-stressed broilers' growth performance and liver health. It improved antioxidant capacity, inhibited the inflammatory response, down-regulated lipogenesis-related genes, and up-regulated lipolysis-related genes, helping alleviate hepatic lipid metabolism disorders induced by heat stress. These results provide a theoretical basis for using COS to treat heat-stress-induced hepatic lipid metabolism disorders in broilers.	(Lan et al., 2023)
0, 1, 2, and 3 g/kg feed	Antioxidative capacity, anti-inflammatory impact, growth performance, and haematological and biochemical indices	Increased levels of COS from 1 g/kg feed to 3 g/kg feed exhibited a decrease in malondialdehyde (MDA) content, thus showing increased antioxidative capacity. Dietary COS 3 g/kg feed showed the lowest levels of pro-inflammatory cytokines (IL-1β and TNF-α) and the highest level of anti-inflammatory cytokines, indicating a more potent anti-inflammatory effect with increasing COS level. Dietary COS 2 and 3 g/kg led to improved body weight gain compared to the COS 1 g/kg feed, indicating that higher doses of COS may improve growth performance more effectively. A decrease in serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), cholesterol, and triglycerides was seen across all dietary COS levels. COS 3 g/kg feed showed the most significant decreases, thus reflecting better liver health with increased COS level. Decreased ratios of right ventricle to body weight and right ventricle to total ventricle were seen with increased COS levels, indicating that higher doses of COS may have more substantial cardioprotective effects.	(Fathi et al., 2023)

COS; chitosan oligosaccharides

Figure 1 demonstrates the role of chitosan oligosaccharides (COS) as dietary antioxidants in broiler chicken nutrition. These include a significant decrease in low-density lipoprotein (LDL) and improved immunity and antioxidant capacity. This dietary COS improves development and nutrient digestibility in broiler chickens by reducing inflammation and oxidative stress. The outcomes of the broiler chicken's increased weight gain, decreased feed intake, and increased carcass production are evident. Additionally, it raises serum glucose and protein concentrations in broilers, suggesting that it may have cardioprotective benefits and improve general health.

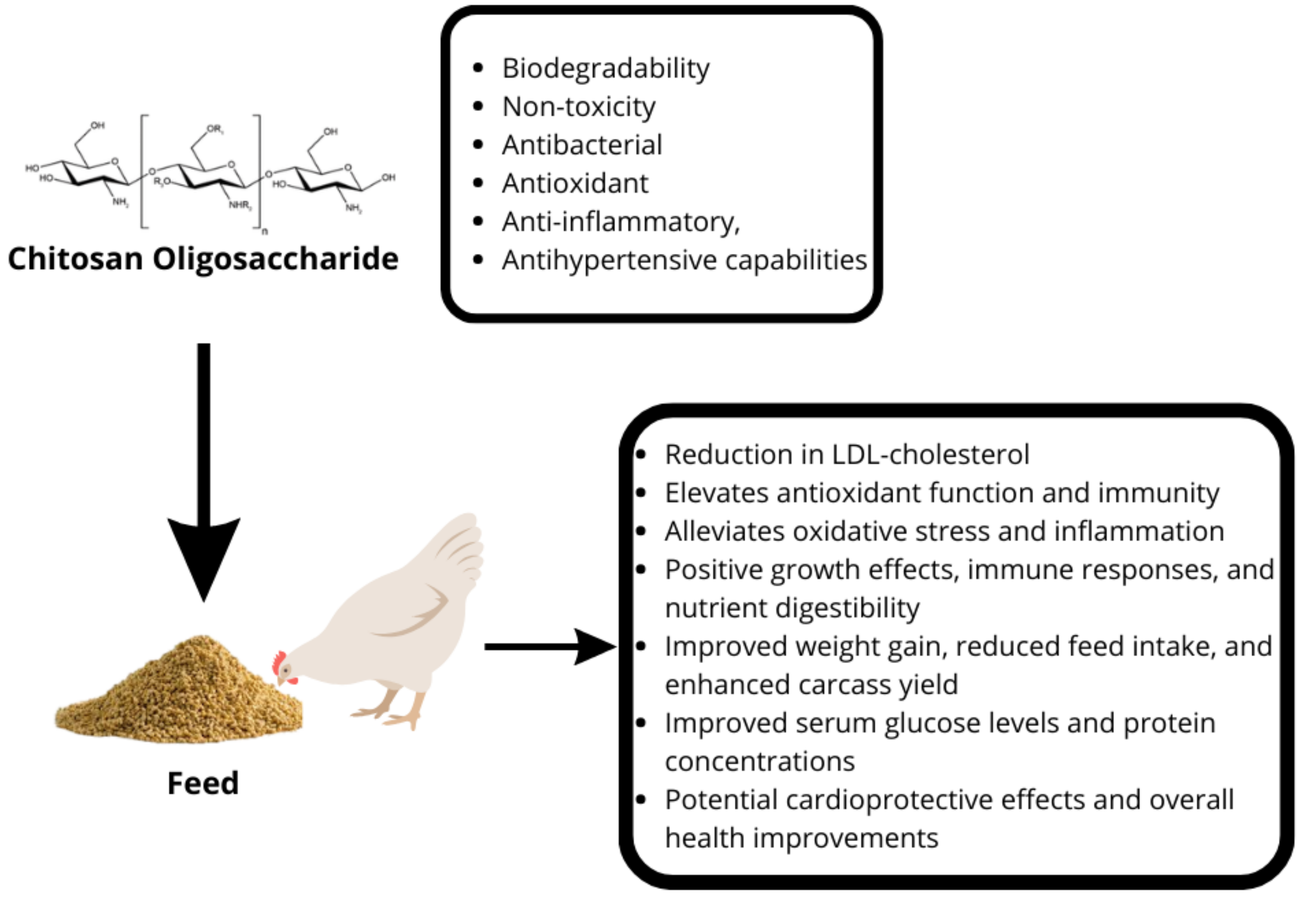

Figure 1 - Role of chitosan oligosaccharides as dietary antioxidants in broiler chicken nutrition

Dietary chitosan oligosaccharides for enhanced broiler performance

The dietary of 125 mg/kg of chitosan oligosaccharides (COS) increased average daily gain (ADG) by 5.9% and improved nutrient digestibility by enhancing gut function (Li et al., 2007). Moreover, the research conducted by Osho and Adeola (2020) presents substantial evidence of the advantageous impacts of dietary COS at a dosage of 1 g/kg feed on broiler chickens, particularly when subjected to stress conditions generated by dexamethasone (DEX). According to a study conducted by Osho and Adeola (2020), including dietary DEX resulted in a significant reduction of 75% in the average body weight gain of broilers that did not receive dietary COS. Nevertheless, upon administering a diet enriched with 1 g/kg COS to the broilers, it was shown that the average body weight gain was reduced by approximately 49%. Consequently, the dietary COS exhibited a statistically significant reduction in the weight loss associated with stress. A similar tendency was also noted in the intake of feed. The broilers exhibited a notable decline in feed intake during periods of DEX-induced stress. However, the extent of this loss in feed intake was comparatively less prominent when the broilers were provided with a dietary COS. Similarly, Tufan and Arslan (2020) reported that dietary COS improved the carcass yield, particularly at the 50 ppm level. Furthermore, according to Fathi et al. (2023), dietary COS 3 g/kg feed showed the best feed conversion ratio.

Osho and Adeola (2020) also reported that dietary chitosan oligosaccharides (COS) effectively alleviated the impact of dexamethasone on the ileal digestibility of dry matter and energy in broiler chickens. It indicates that including COS in the broilers' diet contributed to preserving their capacity to effectively absorb nutrients (dry matter and energy) from their feed, even when exposed to stressful conditions generated by dexamethasone (DEX). The administration of COS was found to positively impact gut health, as indicated by observed alterations in the jejunum's morphology, a small intestine component. Dietary COS resulted in a favourable impact on the morphology of the jejunal region, as seen by the enhancement of villus structure, hence augmenting the capacity for nutrient absorption. Additionally, the COS diet positively affects maintaining a harmonized intestinal barrier function, which may confer protection against the invasion of pathogenic microorganisms in the gut. Similarly, Fathi et al. (2023) reported the positive impact of COS on the intestinal digestibility of dry matter and energy. However, a recent study reported that dietary COS decreased the digestibility of dry matter and crude fat in the dosage 100 ppm COS group compared to the no addition of COS group in broiler. Similarly, organic matter digestibility was reduced in the dosage of COS 50 ppm and 100 ppm groups compared to the no addition of COS group (Tufan and Arslan, 2020).

The dietary chitosan oligosaccharides (COS) has been shown to alleviate the adverse effects of stress on gut health. It improves growth performance, nutrient digestibility, jejunal morphology, gene expression, and plasma antioxidant enzymes (Osho and Adeola, 2020). COS have also been found to regulate intestinal microflora, enhance protein digestion and absorption, and improve growth and feed conversion efficiency in broiler chickens (Nuengjamnong and Angkanaporn, 2018). Chitosan oligosaccharides exhibit antibacterial properties and can penetrate biofilms, leading to enhanced biofilm killing (Lu et al., 2014). They also perform various biological activities, such as inhibiting the growth of bacteria and fungi, exerting antitumor activity, and acting as immunopotentiation effectors (Choi et al., 2004).

Impact of chitosan oligosaccharides on biochemical and antioxidative parameters in broilers

The potential biological features of chitosan oligosaccharides (COS) have garnered researchers' interest. The evaluation of the antioxidant activity of COS involved the utilization of various indices, including Glutathione Peroxidase, Superoxide Dismutase, Glutathione, Total Antioxidant activity, Inhibition of Hydroxy Radical, and Malondialdehyde. Xiaocong et al. (2017) emphasized the positive impact of dietary COS on the antioxidative capabilities of broilers. This observation was further supported by Osho and Adeola (2020), who reported increased activities of specific enzymatic antioxidants that play a crucial role in safeguarding cells against oxidative stress. Moreover, Deng et al. (2008) underscored the significance of COS in enhancing the immune response of broiler chickens, while Al-Surrayai and Al-Khalaifah (2022) shed light on its diverse range of advantages, encompassing antibacterial characteristics as well as its ability to regulate lipid levels.

Chitosan and its derivatives, such as chitosan oligosaccharides (COS), have been extensively recognized for their diverse biological activities. One of the distinguishing characteristics of chitosan is its capacity to modulate lipid metabolism, potentially through its interactions with lipids and bile acids, so it interferes with lipid digestion and absorption. According to the postulation of Keser et al. (2012), these qualities may be responsible for the observed decreases in low-density lipoprotein (LDL) cholesterol. Additionally, the antioxidative mechanism of COS may arise from its polycationic properties, which allow it to effectively counteract reactive radicals, thus safeguarding cells against oxidative harm.

Dietary chitosan oligosaccharides (COS) have demonstrated favourable results in yellow-feather broilers exposed to elevated ambient temperatures. According to the research findings, the antioxidative properties of COS are mostly attributed to its ability to eliminate reactive oxygen species. COS exhibits a protective effect against lipid degradation by reducing Malondialdehyde levels. Furthermore, the augmentation of antioxidant enzymes such as Superoxide Dismutase and Glutathione Peroxidase suggests that COS plays a role in bolstering the body's intrinsic antioxidative mechanisms (Lan et al., 2020).

Moreover, the anti-inflammatory properties of chitosan oligosaccharides (COS) can be shown in its capacity to regulate cytokines. The observed effect is supported by a reduction in pro-inflammatory markers and an elevation in anti-inflammatory markers, as demonstrated in the study conducted by Lan et al. (2020). Stress, including stress generated by exposure to low temperatures, has the potential to trigger a series of inflammatory reactions within the broiler. In the circumstances mentioned earlier, COS has exhibited noteworthy characteristics. The study conducted by Fathi et al. (2023) demonstrated that dietary COS can mitigate the adverse effects of stress by modulating oxidative stress indicators and promoting lipid profiles.

Dietary chitosan oligosaccharides as a strategy to mitigate stress and inflammatory responses in broilers

Dietary chitosan oligosaccharides (COS) have attracted considerable attention due to their potential involvement in altering physiological responses during periods of stress. The study by Osho and Adeola (2020) aimed to examine COS's impact on broilers' mRNA expression patterns. Their study revealed an increased expression of essential proteins, including zonula occludens-1, zonula occludens-2, claudin-1, and occludin. These proteins play a crucial role in preserving the integrity of the gut epithelium by regulating tight junctions. The observed modification suggests a potential alleviation of gastrointestinal distress. Moreover, the study conducted by the researchers demonstrated a reduction in the levels of pro-inflammatory markers, including tumor necrosis factor-alpha, interferon-gamma, and toll-like receptor-4, in individuals affected by coccidia. This finding suggests that COS possesses anti-inflammatory properties.

The study by Chang et al. (2020) aimed to evaluate the effectiveness of chitosan oligosaccharides (COS) in mitigating the adverse effects of heat stress in broiler chickens. In addition to maintaining growth parameters and liver functions, COS has shown direct antioxidative capabilities. As mentioned above, the phenomenon was observed through an increase in muscle glycogen levels, indicating a decrease in muscle glycogen glycolytic metabolism and an improvement in muscle antioxidant defences. Specifically, the study detected an increase in the levels of antioxidant enzymes, such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px), as well as a decrease in the concentration of malondialdehyde, which is a recognized indicator of lipid peroxidation. Chitosan Oligosaccharides' antioxidative capacity becomes vital due to the heightened oxidative stress under unfavourable settings, resulting from escalated reactive oxygen species (ROS) production. The study by Lan et al. (2020) supports the idea that COS effectively reduces oxidative stress indicators and regulates the inflammatory response in severe stress situations.

In a following investigation by Lan et al. (2023), a more comprehensive analysis was conducted to elucidate the effect of chitosan oligosaccharides (COS) in broiler chickens subjected to heat stress. The focus was on mitigating the adverse effects caused by stress, leading to enhancements in growth patterns and physical measurements. The anti-inflammatory effects of COS were seen by regulating inflammatory markers, resulting in a decrease in IL-1β and IL-6 levels and an increase in IL-10 levels. Furthermore, the compound COS enhanced the antioxidant defence mechanisms, highlighting its potential to alleviate the effects of heat stress.

In the study by Swiatkiewicz et al. (2015), they investigated the potential utilization of chitosan and its oligosaccharide derivatives in the context of chicken and swine feed. The data made by the researchers emphasized the potential of chito-oligosaccharide in augmenting the immune response in hens, surpassing the efficacy of traditional supplements such as chlortetracycline.

Influence of chitosan oligosaccharides on liver function and metabolic health in broilers

Numerous research studies have shed light on the therapeutic effectiveness of chitosan oligosaccharides (COS) in regulating hepatic functions and mitigating oxidative stress. The study conducted by Lan et al. (2023) provided a comprehensive understanding of the effects of dietary COS on the upregulation of nuclear factor erythroid related factor 2 (Nrf2) and catalase (CAT) activity, which play a crucial role in antioxidant activity. The observed increase suggests that COS may have the ability to enhance the liver's antioxidant capacity, protecting it from oxidative stress and its negative consequences. Interestingly, COS also demonstrated proficiency in regulating lipid metabolism. Through the downregulation of genes involved in lipogenesis, such as sterol regulatory element-binding protein 1c (SREBP-1c), acetyl-coenzyme carboxylase (ACC), and fatty acid synthase (FAS), and the simultaneous upregulation of genes associated with lipolysis, COS appears to have the potential to correct disruptions in hepatic lipid metabolism, particularly those caused by heat stress. The decrease in blood triglycerides, total cholesterol, and low-density lipoprotein (LDL) cholesterol levels demonstrated the regulating ability of COS. These changes are commonly observed under heat stress and indicate a disruption in lipid metabolism.

Consistent with the earlier research, Chang et al. (2020) emphasized the antioxidative characteristics of chitosan oligosaccharides (COS). The research elucidated that COS can enhance the functioning of key antioxidant enzymes, hence strengthening the body's defence mechanism against oxidative stress. Additionally, COS may mitigate excessive fat accumulation in the liver, thereby protecting against developing fatty liver illnesses. The preventive nature of COS was further supported by the observed decrease in serum levels of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) - enzymes that generally increase in cases of liver diseases.

In their study, Lan et al. (2020) showed the efficacy of chitosan oligosaccharides (COS) as a powerful antioxidant agent, thereby highlighting the significance of further exploration in this area. The study demonstrated a decrease in the levels of malondialdehyde (MDA), an indicator of reduced oxidative damage and lipid peroxidation in the liver, following the addition of COS. Simultaneously, the administration of COS increased the levels of crucial antioxidant enzymes such as Superoxide Dismutase and Glutathione Peroxidase. These enzymes are crucial in neutralizing harmful oxidative substances and reducing oxidative stress. Although the research did not explicitly investigate the impact of COS on lipid metabolism, the observed decrease in MDA levels suggests a potential reduction in lipid peroxidation, indicating a potentially beneficial influence on lipid metabolic pathways.

Ayman et al. (2022) provided a comprehensive analysis of the various changes in blood biochemical markers following chitosan oligosaccharides (COS) administration. Their findings shed light on the impact of dietary COS on liver function, hepatic antioxidant capacity, and lipid metabolism. The COS was observed to reduce serum total cholesterol and triglyceride levels, potentially inhibiting cholesterol production, facilitating lipid excretion, or modulation of lipid metabolic enzymes. Furthermore, the increased serum concentrations of protein, albumin, and globulin following the administration of dietary COS suggest an improvement in protein metabolism, possibly due to higher protein digestibility. Further inquiry is warranted to explore the ancillary observation of a minor increase in aspartate aminotransferase (AST) levels with a higher dosage of corticosteroids. However, it is worth noting that these levels remained within physiological limits, suggesting that this effect is benign in origin.

Evaluating the implications of chitosan oligosaccharides on meat quality and carcass traits

Recent research has demonstrated that including chitosan oligosaccharides (COS) as a dietary for broiler chickens has significantly impacted muscle quality and carcass characteristics. In a study conducted by Chang et al. (2020), it was noted that broiler chickens experiencing heat stress and receiving dietary COS demonstrated an elevated muscle pH after 24 hours postmortem. This observation is considered advantageous for meat quality, as it is associated with enhanced water-holding capacity, texture, and overall meat quality. The increase in muscle glycogen levels resulting from dietary COS enhances the muscle's capacity for energy storage. In addition, it was noted that heat stress with COS led to a decrease in lactate content, potentially influencing the higher pH values seen and thereby improving the overall quality of the meat. One notable finding from this study is that adding COS can effectively decrease cooking loss in broilers, indicating that the meat preserves a more significant proportion of its weight during the cooking process, resulting in a more succulent final product.

Tufan and Arslan (2020) investigated the impact of chitosan oligosaccharides (COS) on carcass features. The researchers observed notable improvements in the dressing percentage of broilers administered COS at 50 ppm and 100 ppm compared to the control group. Upon analyzing the components of the carcass, it was seen that there was a significant increase in the weight of the wings for both groups exposed to COS concentration. Additionally, there was a notable elevation in the weight of the breast and legs, specifically for the group exposed to a COS concentration of 50 ppm, compared to the control group. Nevertheless, introducing dietary COS did not significantly alter the fatty acid composition of the breast meat. However, the following study should have offered additional information regarding muscle pH, redness, cooking loss, or shear force, which may have resulted in an incomplete comprehension of COS's effects on meat quality.

The findings of Chang et al. (2022) provide additional evidence in support of the results mentioned earlier, indicating that the pH levels measured at 45 minutes and 24 hours after death were comparatively higher in the group dietary COS compared to the group exposed exclusively to heat stress. The association between an increased pH level in meat and enhanced meat quality is commonly observed. Furthermore, the intensity of the red colouration in the meat, a characteristic that consumers commonly associate with the state of freshness, exhibited greater prominence in the group that received dietary COS. The experimental group demonstrated a reduction in cooking loss, suggesting improved moisture retention during cooking, resulting in a more succulent meat product. Furthermore, it was observed that the group addition with COS demonstrated a decreased shear force, indicating a higher level of tenderness in the flesh.

The potential methods by which COS enhances meat quality may be linked to its capacity to enhance antioxidant defences, alleviate oxidative stress, and strengthen immunological function, as proposed by Domínguez et al. (2019). The results, as a whole, emphasize the potential of COS addition in enhancing the quality of poultry meat. However, additional comprehensive investigations may be necessary to understand the full range of its impact.

CONCLUSION

Dietary chitosan oligosaccharides (COS) in the feed of broiler chickens have been found to have several advantages, such as improved growth performance, increased antioxidative ability, and enhanced immunological responses. It can be concluded that dietary COS in broiler chickens in doses ranging from 200 mg to 1000 mg/kg feed has a positive effect on growth performance, antioxidative properties, regulation of lipid metabolism, ability to mitigate stress, impact on meat quality, and carcass traits, but exceeding 2.5 g/kg feed may significantly impair in growth performance in the broiler.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Authors' contribution

R. P. Harahap had the idea for the article and drafted it, and performed the literature search.

M. M. Sholikin performed supervision and editing.

Sadarman critically revised the work.

Conflict of interests

The authors declare that they have no competing interests.

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