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Dietary Quercetin for Enhanced Broiler Performance- A Review

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ABSTRACT

Quercetin, a naturally occurring flavonoid, has received consideration for its possible benefits in chicken nutrition because of its anti-inflammatory, gut-health-promoting, and antioxidant properties. This review summarizes current research on quercetin supplementation in broiler chickens, focusing on its implications on growth performance, immunological response, gut health, and carcass quality. Quercetin has been shown in studies to improve body weight gain, feed conversion efficiency, and nutrient absorption while also reducing oxidative stress by upregulating antioxidant enzymes like as superoxide dismutase and glutathione peroxidase. Furthermore, it aids immunological regulation by lowering inflammatory cytokines and increasing disease resistance. Quercetin also improves gut microbiota composition and shape, resulting in greater digestive health. Furthermore, it enhances meat quality by lowering lipid peroxidation, improving texture, and increasing shelf life. Findings indicate quercetin as a possible natural substitute to antibiotics in broiler feed supplement, which aligns with the growing need for sustainable, antibiotic-free poultry production. However, additional research is needed to enhance its bioavailability, administration approaches, and long-term effects in commercial applications. Future research should concentrate on improving its bioavailability and determining its economic viability in large-scale commercial applications.

KEYWORDS: Antioxidant, Broiler chicken, Gut microbiota, Poultry feed additives, Quercetin

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INTRODUCTION

A naturally occurring flavonoid, quercetin can be found in a wide variety of fruits, vegetables, and grains. Chemically, it is a polyphenol, with a hydroxylated aromatic structure that contributes to its strong antioxidant properties. Quercetin is valued for its ability to scavenging free radicals, reducing oxidative damage and lipid peroxidation. Quercetin reduces inflammation by modulating the signalling pathways like NF-κB decreasing pro-inflammatory cytokines. Liu et al. (2021) found that quercetin binds to the γ-subunit of AMPK in a manner structurally similar to ZMP, a known AMPK activator, suggesting that quercetin induces allosteric activation of AMPK and thereby triggers downstream signalling events; in turn, activated AMPK increases cellular NAD+ levels, which enhances the deacetylase activity of SIRT1, leading to deacetylation of the NF-κB p65 subunit and suppression of its nuclear translocation and pro-inflammatory transcriptional activity. As a result, through this AMPK/SIRT1/NF-κB axis, quercetin significantly reduces the production of key pro-inflammatory cytokines, such as TNF-α (by 35–48%), IL-1β (by 28–42%), and IL-6 (by 31–50%) in experimental models, thereby exerting potent anti-inflammatory effects.

Studies have demonstrated that quercetin can protect broiler chickens from inflammatory damage and restore gut microbial diversity, hence promoting intestinal barrier functioning (Sun et al., 2022). It also increases antioxidant enzyme activities including superoxide dismutase and glutathione peroxidase, which improve the oxidative stability of chickens under stress (Dong et al., 2020). Quercetin's biological properties make it a good choice for usage as a natural feed supplement, replacing synthetic growth promoters and antibiotics while meeting the growing demand for sustainable chicken production (Saeed et al., 2017). Quercetin has been found to increase meat quality, growth performance, and gut microbiota, all of which contribute to the general health of chicken (Benzertiha et al., 2019; Hussien et al., 2021; Walk et al., 2021; Janocha et al., 2022; Selle et al., 2023).

Various bio-enhancers and nano-formulations (Beski et al., 2015, Divani et al., 2018; Marcincak et al., 2018) has been tried as additives in broiler nutrition. In addition, it has been highlighted that mechanistic research and long-term trials are necessary to gain a deeper understanding of quercetin's molecular activities and cumulative effects over time.

Challenges in Broiler Production

Broiler production has several challenges that have a substantial impact on growth, health, and total output. Among these obstacles, oxidative stress and gut health concerns are especially significant. An imbalance between the production of reactive oxygen species (ROS) and antioxidant defence leads to oxidative stress, which damages cells and reduces physiological activity. (Tompkins et al., 2022). This illness is aggravated by environmental stressors such as high temperatures, which are frequent in tropical and subtropical areas. Furthermore, gut health is essential for good food absorption and overall well-being in chickens. Gastrointestinal system is sensitive to many pathogens, which can cause illnesses such as necrotic enteritis and dysbiosis (Obianwuna et al., 2023). These gut health conditions limit feed efficiency and raise mortality rates, creating considerable economic challenges to chicken breeders. In order to overcome these challenges, antibiotics as growth promoters have long been utilized; however, growing customer demand for antibiotic-free products and worries about antibiotic resistance have led to a change in approach. This has resulted in an increased the search for natural feed additives, such as phytochemicals, for improving chicken performance along with their health (Moustafa et al., 2021).Various alternatives to antibiotic growth promoters which is equally effective on growth performance, nutrient utilization and carcass characteristics for rearing broiler poultry like plant extracts and essential oil blend (Devi et al., 2018); dietary neem (*Azadirachta indica*) and kadi (*Murraya koenigii*) leaf powder (Khulbey et al., 2015); garlic (*Allium sativum*) and tulsi (*Ocimum sanctum*) leaf powder supplementation (Kumar et al., 2016) has been tried and found efficient in their role.

Quercetin as a Potential Solution

Quercetin, a flavonoid with five hydroxyl groups, is a potent antioxidant and anti-inflammatory compound that scavenges free radicals, boosts antioxidant enzymes, and reduces oxidative stress, thereby improving broiler growth and health (Table 1) (Vinnarasi et al., 2020; Ying et al., 2020; Tan et al., 2022). It enhances gut health by moderating inflammation, preserving intestinal barrier integrity, and promoting beneficial gut microbiota, making it an effective natural alternative to antibiotics in poultry nutrition (Ying et al., 2020; Moustafa et al., 2021). Quercetin also upregulates antioxidant enzymes (SOD1, GSH-Px), nutrient transporters, improves nutrient digestibility, immune response, calcium and phosphorus metabolism, and meat quality, thus boosting production efficiency in broilers when supplemented at 200–400 ppm (Abdel-Latif et al., 2021; Wang et al., 2022)

Metabolism of quercetin

Quercetin is extensively metabolized mainly in the liver and intestines, commonly existing as glycosides which enhance its solubility and bioavailability. After ingestion, it undergoes phase I metabolism (oxidation, reduction, hydrolysis) and phase II metabolism (glucuronidation, sulfation, methylation) resulting in diverse metabolites that influence its biological activity and pharmacokinetics (Materska, 2008; Ozgen et al., 2016). In poultry, quercetin absorption is affected by diet, phytochemicals, and gut microbiota, with dietary fibers and flavonoids enhancing uptake, but gut environment complexity requires tailored formulations for optimal bioavailability (Materska, 2008; Jurasekova et al., 2014; Ilyich et al., 2018; Brovarets & Hovorun, 2019; Tyagi et al., 2020).

Despite its many advantages, quercetin has low water solubility, limiting its gastrointestinal absorption (Materska, 2008; Ozgen et al., 2016; Shanmugasundaram and Roza, 2022). It undergoes rapid liver metabolism forming quercetin glucuronides and sulfates, resulting in low plasma levels and reducing its active biological availability (Rupasinghe et al., 2010; Seruga & Tomac, 2017; Sun et al., 2022). This extensive first-pass metabolism significantly diminishes the amount of quercetin available for biological effects.

Strategies to improve quercetin's efficacy include encapsulating it in nanoparticles to enhance solubility, stability, and sustained release, as shown by Algan and Karatas (2023). Co-supplementation with compounds like piperine or curcumin blocks metabolic enzymes and boosts bioavailability; Patel et al. (2021) demonstrated improved pharmacokinetics of marbofloxacin in broilers with quercetin-piperine. Additionally, dietary inclusion of quercetin-rich extracts such as apple skin enhances absorption (Rupasinghe et al., 2010). Variations in dosage (100–600 mg/kg) and supplementation duration, as well as environmental factors like temperature and housing, influence its effects on meat quality, immune response, and growth performance (Rupasinghe et al., 2010; Patel et al., 2021; Sun et al., 2022; Ahammad & Kim, 2024). Nanoparticles, such as quercetin-loaded Feƒ O„ , significantly improve immune and antioxidant defenses in broilers, reducing pathogen burden and enhancing performance (Al-Nasser et al., 2024).

Quercetin as antioxidant agent

Quercetin enhances antioxidant status in broiler chickens by increasing enzyme activities such as glutathione peroxidase (GSH-Px) and superoxide dismutase (SOD), while reducing oxidative stress markers like malondialdehyde (MDA), which is essential for maintaining health and production, especially under stress (Dong et al., 2020). Supporting evidence from other models shows quercetin's effectiveness in lowering oxidative damage, such as reduced MDA in rat spleen tissue exposed to titanium dioxide nanoparticles and decreased oxidative stress in elderly rats' cerebral cortex via enhanced antioxidant enzymes combined with calorie restriction (Jaber, 2023).

Oxidative stress is a major constraint in poultry production, commonly triggered by nutritional imbalances, heat stress, and pathological conditions (Mishra & Jha, 2019). Quercetin, a potent antioxidant, effectively scavenges reactive oxygen species (ROS), thereby reducing oxidative damage linked to metabolic and degenerative diseases (Bukowska & Duchnowicz, 2022; Bellavite, 2023). It also enhances the activity of endogenous antioxidant enzymes—glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD)—and inhibits pro-oxidative enzymes such as xanthine oxidase and lipoxygenase (Chiu et al., 2023; Olla et al., 2023).

In broiler chickens, quercetin supplementation is well recognized for mitigating oxidative stress and improving overall health and performance. Abdelrahman et al. (2022b) reported significant reductions in malondialdehyde (MDA), a key marker of lipid peroxidation, alongside improved growth and meat quality. Similarly, Liu et al. (2013) demonstrated that quercetin suppresses lead (Pb)-induced oxidative stress by reducing ROS production, increasing total antioxidant capacity (TAC), and upregulating phosphoinositide-3-kinase (PI3K) and phosphorylated protein kinase B (PKB/Akt) activity. Quercetin-containing seaweed supplements have also shown strong antioxidant effects, with brown seaweed (BS) and green seaweed (GS) enhancing antioxidant activity by 55.19% and 25.74%, respectively, compared to unsupplemented controls (Zhong et al., 2020; Azizi et al., 2023).

Table 1. Effect of dietary quercetin on health, meat quality and growth performance of chicken

Characteristics	Dose rate of quercetin	Observed effect	References
Antioxidant	1g/kg with high energy challenged diet	Reduced metabolic stress, oxidative stress, and lipotoxicity from high-energy diets	Parmar et al., 2022
	0.02%, 0.04% and 0.06% with Streptozotocin	Mitigated STZ-induced oxidative stress by regulating antioxidant enzymes and lowering MDA and NO levels.	Ying et al., 2020
	200-800 ppm	Reduced oxidative stress from oxidized oil and prevented pathogen invasion	Dong et al., 2020
Antioxidant and anti-inflammatory	200 mg/kg along with LPS challenged diet	Alleviated LPS-induced inflammation and apoptosis by modulating gut microbiota and immunity.	Sun et al., 2020
	0.5 g/kg	Antioxidant, anti-inflammatory, and antiapoptotic properties and reduced nephrotoxicity	Abdelrahman et al., 2022a
Growth promoter and antioxidant	250, 500, and 1,000 mg /kg	Increased body weight gain, antioxidant capacity, and SOD; reduced MDA levels	Zhang et al., 2020
	200-600 ppm	Increased weight gain, feed intake, immunity, and antioxidant status	El-Kazaz et al., 2024
	0.5mL /kg	Improve growth performance and feed conversion ratio	Ugwuoke et al., 2024
	200-400 ppm	Improved the intestinal morphometry and growth traits	Abdel-Latif et al., 2021
Meat quality and anti-oxidant	0.2, 0.4, and 0.6 g/kg	Enhanced meat quality and protected against lipid oxidation and fat deposition	Wang et al., 2022
	500 and 1000 mg/kg	Improved antioxidant capacity, muscle protein stability, and edibility.	Deng et al., 2024

Quercetin boosts key antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase (GPx), helping neutralize reactive oxygen species and reduce oxidative stress. Studies in rats exposed to doxorubicin or hypertension show that quercetin increases SOD and GPx activity, thereby limiting oxidative damage and strengthening endogenous defence mechanisms (Farag et al., 2021; Maksymchuk et al., 2023).

Regulation of Inflammatory Routes

Quercetin plays a key role in controlling inflammation (Table 2) by inhibiting nuclear factor kappa B (NF-êB), a major transcription factor involved in producing pro-inflammatory cytokines such as IL-1â, TNF-á, and IL-6 (Ozbek et al., 2015). It also modulates mitogen-activated protein kinase (MAPK) pathways, reducing inflammation and promoting tissue repair. In broilers, quercetin supplementation decreases serum markers like creatinine, BUN, and AST, lowers inflammatory cytokine expression, and enhances immune response and health (Kim et al., 2010; Al-Nasser et al., 2024). Additionally, quercetin exhibits antimicrobial effects by suppressing pathogenic bacteria, improving gut health, and reducing infection risks. These anti-inflammatory and antimicrobial actions are vital for mitigating stress-induced inflammation in poultry production.

Table 2. Role of dietary quercetin in regulating inflammatory response in broiler chicken

Quercetin dose	Anti-inflammatory action	Reference
LPS-treated, 200 -500 mg/kg	Lowers pro-inflammatory cytokines (TNF-α, IL-1β, IL-6, TLR-4) and boosts protective proteins (ZO-1, Bcl-2)	Sun et al., 2022
Basal diet + quercetin @1 g/kg	Reduces liver expression of IL-1β, IL-6, and TNF-α mRNA.	Parmar et al., 2022
10 μg/mL LPS+1 mM ATP and 5, 10, and 20 μM quercetin	levels of TLR4, NLRP3, caspase-1, gasdermin D, IL-1β, IL-18, IL-6, TNF-α; inhibits NF-κB p65 phosphorylation; increases cell migration and ZO-1/claudin expression; lowers late apoptotic cells	Zhang et al., 2022

Effects on Immunomodulation

Quercetin enhances immune function in broilers by increasing anti-inflammatory markers and reducing pro-inflammatory cytokines, thus strengthening disease resistance (Table 3) (Khampeerathuch et al., 2018). It also raises blood immunoglobulin levels, indicating a stronger humoral immune response (Sun et al., 2020; Abdel-Latif et al., 2021).

Table 3. Immunomodulatory effect of quercetin in chicken

Quercetin Dose	Inflammatory markers involved	References
20-200 ppm	Decreased IgA and IgM levels	Kim et al., 2015
50 μM quercetin hydrate of >95% purity	Increased anti-inflammatory gene expression (IL6, IL8L1, IL8L2, IL18, CCL4, LITAF, MIF)	Khampeerathuch et al., 2018
0.02- 0.06%	Raised TNF-α, TRAF-2, TNFRSF1B, NF-κBp65, IFN-γ mRNA; decreased IκB-α mRNA ($P < 0.05$)	Yang et al., 2020
200 mg/kg	Reduced inflammatory markers and apoptosis genes induced by LPS; increased tight junction proteins and Bcl-2	Sun et al., 2022
0.02-0.06%	Modulated oxidative stress, raised insulin, activated PI3K/PKB pathway genes for glucose metabolism and oxidative damage reduction	Ying et al., 2020; Abdelrahman et al., 2022b
200-600 ppm	Enhanced IgM, IgA secretion; stimulated humoral immunity and upregulated IL-4, IFN-γ, TLR2, and TNF-α in spleen	El-Kazaz et al., 2024

Li and Xu (2008) identified quercetin as the key antimicrobial agent in lotus leaves extract, with minimum inhibitory concentrations of 0.625 mg/mL for *Aggregatibacter actinomycetemcomitans* and *Fusobacterium nucleatum*, 1.25 mg/mL for *Actinomyces viscosus* and *Porphyromonas gingivalis*, and 2.5 mg/mL for *Actinomyces naeslundii*. Rauha et al. (2000) reported quercetin's inhibition against various pathogens including Aspergillus niger, *Bacillus subtilis*, *Candida albicans*, *Escherichia coli*, and *Staphylococcus aureus*. In broilers, quercetin supplementation (200–800 mg/kg) enhanced immunoglobulin levels, reduced *coliform* and *Clostridium perfringens* counts, and increased beneficial *Lactobacillus* populations, improving gut health and immune status (Abdel-Latif et al., 2021). This immunomodulatory and antimicrobial action is critical for poultry health under intensive production stressors (Table 4).

Quercetin supplementation in broiler diets has been shown to enhance disease resistance, particularly against *Clostridium perfringens*, a primary cause of necrotic enteritis. Quercetin-loaded nanoparticles significantly reduced intestinal colonization of *C. perfringens* while boosting the birds' immune and antioxidant defenses (Al-Nasser et al., 2024). Additionally, micellar quercetin improved immunological responses and growth performance in broilers (Ahammad and Kim, 2024).

Table 4. Effect of dietary quercetin on gut microbiota in broiler chicken

Dose	Bacteria type	Possible mechanism	Reference
400 ppm	Promote *Lactobacillus*	Strengthened intestinal barrier by increasing MUC2 expression and secretion	Dong et al., 2020
250-1000 mg/kg	Favours *Lactobacillus* growth	Unabsorbed dietary phenolics and metabolites inhibit pathogens and promote beneficial bacteria like *Lactobacillus* and *Bifidobacterium*	Zhang and Kim, 2020
200, 400, and 800 ppm	Decrease total *coliforms* and *Clostridium perfringens* and increase *Lactobacillus*	Antibacterial action through inhibition of DNA gyrase, bacterial membranes, motility, FAS II pathway, and Ddl enzyme, acting bacteriostatically	Abdel-Latif et al., 2021
0.025% to 0.100%	Reduces *E. coli* levels without affecting *Lactobacillus* or *Salmonella* count	Fermented flavonoids contain lactic and organic acids with antimicrobial synergy	Ahammad and Kim, 2024
300 mg/kg	*Clostridium perfringens* colonization	Quercetin-loaded Fe_3O_4-NPs reduced C. perfringens colonization and virulence gene expression, increased Lactobacillus and Bifidobacterium, upregulated host antimicrobial peptides, and downregulated intestinal inflammatory genes	Al- Naseer et al., 2024

Growth Performance

Quercetin supplementation has been found to significantly enhance growth performance in broiler chickens. Ahammad and Kim (2024) reported that micellar quercetin supplementation dramatically increased body weight gain and feed conversion ratio. Ugwuoke et al. (2024) observed that dietary quercetin at 0.5 mL/kg in the basal diet resulted in the highest final body weight and average daily weight gain. Importantly, quercetin did not affect feed intake significantly, suggesting improved nutrient utilization efficiency.

Feed Conversion Ratio (FCR)

Quercetin supplementation has been shown to improve the feed conversion ratio (FCR) in broilers, reflecting better efficiency in converting feed into body mass. Guar meal which is good source of flavonoid quercetin (Sharma et al., 2011), when included at 15% fermented toasted guar meal in broiler diets, improved FCR comparable to supplements (Lakshmi et al., 2025). Ahammad and Kim (2024) reported that micellar quercetin significantly enhanced FCR, indicating improved feed-to-weight conversion. Goliomytis et al. (2014) also found FCR increases at 0.5 and 1 g/kg quercetin supplementation, suggesting enhanced metabolic feed utilization. Ugwuoke et al. (2024) observed the highest weight gains at 0.5 mL/kg, indicating optimal dosage ranges for maximizing growth. Quercetin may also interact beneficially with other compounds like vanillin and 7-hydroxycoumarin to improve broiler meat mineral content and overall performance (Zavialov et al., 2023).

Gut Health

Quercetin supplementation improves gastrointestinal health in broilers by enhancing intestinal morphology, including increased villus height and villus height-to-crypt depth ratio, which supports better nutrient absorption (Abdel-Latif et al., 2021; Sun et al., 2022). It positively modulates gut microbiota by increasing beneficial bacteria and suppressing harmful strains, crucial for optimal feed efficiency and overall health. Agarwal et al. (2022) showed quercetin enhances brush border membrane architecture, increasing goblet and Paneth cells vital for gut function. Amevor et al. (2022) found dietary quercetin and vitamin E improved intestinal structure in older hens, promoting nutrient absorption through increased crypt depth and villi height. Studies also highlight quercetin's antioxidant properties improve nutrient utilization and overall health, reducing heat stress impacts in broilers (Parmar et al., 2019; Attia et al., 2023).

Quercetin effectively regulates gut microbiota, promoting beneficial bacteria while inhibiting pathogenic strains, which is vital for gut health and nutrient absorption (Shi et al., 2022). Ghimire et al. (2021) found that combining rice bran and quercetin increased beneficial gut bacteria and reduced harmful *Enterobacteriaceae*. This microbiota balance, along with quercetin's antioxidant properties, supports optimal gut health and nutrient utilization in broilers.

Improvement of Meat Quality Parameters

Quercetin effectively reduces lipid oxidation in broiler chicken meat, enhancing its shelf life and sensory qualities. Delles et al. (2014) showed that quercetin and other dietary antioxidants significantly lowered lipid oxidation markers such as thiobarbituric acid reactive substances (TBARS) in chicken breast meat. Similarly, Gumus and Gelen (2023) reported that supplementation with quercetin-containing thyme and rosemary essential oils dramatically decreased TBARS levels in both drumstick and breast meat during storage, thereby improving oxidative stability and meat quality. This antioxidant action of quercetin is crucial for maintaining meat freshness and extending shelf life in poultry production.

Quercetin supplementation has been shown to improve broiler meat tenderness by reducing shear force in thigh and breast muscles, likely through its effects on protein metabolism (Wang et al., 2022). Janocha et al. (2021) also found that quercetin-rich feed additives enhance meat quality, including tenderness, by protecting muscle proteins from oxidative damage during storage. The antioxidant properties of quercetin help maintain muscle integrity, contributing to improved meat softness and consumer acceptance.

Quercetin's antibacterial properties contribute significantly to improving meat safety in broilers by lowering microbial load. Faluyi et al. (2020) reported that red onion, rich in quercetin, reduced microbial counts in unrefrigerated broiler meat, maintaining quality during storage. Dietary quercetin-rich foods decreased bacterial counts in broiler meat. These reductions help safeguard poultry products and reduce food borne illness risks by controlling pathogenic bacteria in meat.

Future Perspectives: Exploring Quercetin's Potential in Broiler Chickens

Although quercetin shows promise as a dietary supplement in broiler nutrition (Table 6), further research is needed to fully understand its mechanisms, long-term benefits, and practical applications. Molecular-level studies are essential to elucidate how quercetin influences gene expression, cellular pathways, and metabolic processes related to immune response, growth, gut health, inflammation, and oxidative stress in broilers (Ahammad and Kim, 2024). Long-term trials are necessary to evaluate cumulative effects on meat quality, health, growth performance, and possible adverse effects or nutrient metabolism alterations, as emphasized by Sierzant et al. (2023).

Table 5. Summary of quercetin role in broiler chicken nutrition

Property	Effect on Broiler chickens	Mechanism involved	Reference
Antioxidant	Improves meat quality and oxidative stability	Enhances antioxidant enzymes, reduces oxidation	Deng et al., 2024
Anti-lipid peroxidation	Reduces liver MDA content	Reduces oxidized lipid by-products	Sierzant et al., 2023
Growth promoter	Increases body weight gain	Enhances T-SOD, T-AOC, reduces MDA	Zhang and Kim, 2020
Gut microbiota modulator	Increases *Lactobacillus*, reduces *coliforms* and *C. perfringens*	Modifies gut environment, upregulates SOD1, GSH-Px	Abdel-Latif et al., 2021
Feed efficiency improver	Improves feed conversion ratio and weight gain	Enhances nutrient utilization	Onu et al., 2024
Lipid metabolism regulator	Reduces abdominal fat content	Downregulates L-FABP, SREBP1, HMGR; upregulates CPT1	Wang et al., 2022
Intestinal morphometry improver	Increases villus height, decreases crypt depth	Enhances gut structure	Sun et al., 2020
Intestinal protector	Reduces LPS-induced oxidative stress in intestines	Activates MAPK/Nrf2 pathway	Sun et al., 2020
Nutrient transporter up-regulator	Upregulates GLUT2, PEPT1, FAS genes	Enhances nutrient absorption	Abdel-Latif et al., 2021
Meat quality enhancer	Reduces cooking and drip loss, improves breast muscle	Improves muscle structure, increases α-helix content	Ahammad and Kim, 2024
Meat tenderness	Increases tenderness and juiciness	Activates PI3K/PKB/AMPK pathway	Wang et al., 2022
Muscle flavor enhancer	Increases inosinic acid (IMP) in muscle	Modifies muscle biochemistry	
Immunomodulator	Ameliorates immunotoxicity from ochratoxin A	Activates PI3K/AKT pathway, reduces apoptosis	Abdelrahman et al., 2021b
Immune response enhancer	Increases TNF-α, improves antibody response	Modulates cytokine production	Zhang and Kim 2020
Blood profile modulator	Increases thyroxine (T4) and lymphocyte levels	Influences hormone and immune cell levels	Ahammad and Kim, 2024
Nephroprotective	Protects against ochratoxin A-induced nephrotoxicity	Suppresses apoptosis via PI3K/AKT pathway	Elhady et al., 2022
Mitochondrial protector	Upregulates mitochondrial DNA copy number genes	Enhances mitochondrial function	Sun et al., 2020
Anti-apoptotic	Reduces proapoptotic gene expression in kidney	Modulates apoptosis-related genes	Elhady et al., 2022

CONCLUSION

Quercetin exhibits diverse benefits in broiler production, including antioxidant effect, growth-promoter agent, factor for enhancing meat quality, modulation of gut microbiota, immunomodulatory factor, and also with metabolic regulatory effects. Its potential as a sustainable, cost-effective feed additive makes it a promising alternative to synthetic feed additives. However, further research is needed to determine optimal dosages, supplementation forms, long-term safety, and mechanisms of action through controlled field trials to ensure its effective integration into commercial poultry production.

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