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Capsicum annuum L. and *Piper nigrum* L. in Poultry Nutrition: Powders, Extracts, and Bioactive Compounds in Dietary Applications

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ABSTRACT This review was conducted to evaluate the potential of *Capsicum annuum* L. and *Piper nigrum* L. as functional phytogenic additives in poultry diets. *C. annuum* contain capsaicinoids, carotenoids, and flavonoids, while *P. nigrum* is characterized by piperine as its major active alkaloid, which collectively contributes to antioxidant, metabolic, and immunomodulatory functions. This review summarizes the major phytochemicals present in *C. annuum* and *P. nigrum*, comparing the efficacy of their processed forms such as powders, solvent extracts, oleoresins, and purified bioactive compounds in poultry. Overall, dietary supplementation with these processed forms has been reported to enhance growth performance, serum lipid profiles, stress-related biomarkers, antioxidant capacity, intestinal morphology, and digestive enzyme activity in broiler chickens, laying hens, and Japanese quail. Variability in responses among studies appears largely dependent on processing form, phytochemical concentration, and bioavailability. In conclusion, this review provides an updated overview of current knowledge and offers strategic perspectives for the practical application of *C. annuum* L. and *P. nigrum* L. as functional phytogenic additives in modern poultry production.

(Key words: antioxidant capacity, *Capsicum annuum* L., growth performance, *Piper nigrum* L., poultry)

INTRODUCTION

Over the past decades, antibiotic growth promoters (AGPs) have been widely incorporated into animal feed to enhance growth performance and suppress intestinal pathogens, thereby reducing the incidence of infectious diseases (Miyakawa et al., 2024). However, increasing concerns regarding the emergence of antibiotic-resistant bacteria and the presence of antibiotic residues in animal-derived products have led many countries to restrict or ban the use of antibiotics in livestock production (Treiber and Beranek-Knauer, 2021). These regulatory actions have resulted in considerable challenges for the poultry industry, including reduced productivity, impaired immune responses, and increased susceptibility to infections. Furthermore, adverse effects such as a deteriorated feed conversion ratio (FCR) and intestinal dysbiosis have frequently been reported following the withdrawal of AGPs in poultry production (Costa et al., 2017; Vera-Álava et al., 2023). These challenges have prompted extensive research into safe and effective alternatives to AGPs (Ayalew et al., 2022). Recent advances in poultry nutrition have highlighted the potential of natural feed additives, particularly phytogenic compounds, probiotics, prebiotics, and other naturally derived substances, as promising substitutes for AGPs (Abdeli et al., 2021). Among these, plant-derived bioactive substances have shown notable benefits in enhancing growth performance, antioxidant capacity, and immune responses in poultry (Obianwuna et al., 2024). Phytochemicals such as flavonoids, essential oils, saponins, and pungent compounds play crucial roles in maintaining intestinal integrity, alleviating oxidative stress, and supporting a balanced gut microbiota, thereby contributing to improved growth and overall health (Madhusankha et al., 2023; Wang et al., 2024). In particularly, plants containing pungent bioactive constituents have drawn scientific attention because of their pronounced physiological and metabolic impacts on growth performance, gut health, and antioxidant capacity (Abdelli et al., 2021). *Capsicum annuum* L., a widely cultivated species of the genus *Capsicum*, is a major source of capsaicinoids, secondary metabolites responsible for characteristic pungency of pepper fruits (Alonso-Villegas et al., 2023). Capsaicin, the principal bioactive

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compound in *C. annuum*, is known for its antioxidant, anti-inflammatory, and lipid metabolism regulating properties (Srinivasan, 2016). Similarly, *Piper nigrum* L., commonly known as black pepper, is a pungent spice of the genus *Piper* containing piperine, an alkaloid responsible for its distinctive flavor and diverse biological functions (Haq et al., 2021). Piperine, a principal alkaloid derived from *P. nigrum*, represents a phytogenic compound of considerable interest because of its multifaceted biological activities, including antioxidant, antimicrobial, anti- inflammatory, and bioavailability-enhancing effects (Ashokkumar et al., 2021). Collectively, these biological properties suggest that *C. annuum* and *P. nigrum*, along with their primary constituents capsaicin and piperine, possess substantial potential as natural alternatives to AGPs by improving growth performance, antioxidant defense mechanisms, and supporting metabolic functions in poultry (Samantaray and Nayak, 2021). *C. annuum* and *P. nigrum* have been incorporated into poultry diets in various forms, including powdered materials, extracts, and purified bioactive compounds (Liu et al., 2021b; Ogbuewu and Mbajiorgu, 2023). These different forms vary in phytochemical composition and bioavailability, which may influence their physiological efficacy (Wang et al., 2024). However, information remains limited regarding the effects of physical form and processing of *C. annuum* and *P. nigrum* on biological efficacy in poultry Therefore, this review aims to explore their potential as functional feed additives in poultry nutrition. Specifically, we summarize the major bioactive compounds identified in these species and their associated physiological functions. In addition, this review comparatively examines the efficacy of *C. annuum* and *P. nigrum* in powdered, extract, and purified bioactive forms, focusing on their roles in growth performance, antioxidant capacity, and metabolic regulation, thereby assessing their practical applicability as natural poultry feed additives.

PHYTOGENIC PLANTS: *CAPSICUM ANNUUM* L. AND *PIPER NIGRUM* L.

1. Botanical Classification and Morphological Characteristics

C. annuum L. belongs to the genus *Capsicum* within the family Solanaceae. The genus comprises approximately 25 species, including *C. annuum*, *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L., and *C. pubescens* Ruiz and Pav. are recognized as the principal cultivated types of economic importance (Hernández Pérez et al., 2020). Archaeological evidence indicates that *C. annuum* was first domesticated in Central and South America, particularly in the Tehuacán Valley of Mexico, around 5,000 to 7,000 B.C., whereas wild chili peppers were consumed as early as 8,000 B.C. (Kraft et al., 2014). The genus *Capsicum* exhibits remarkable biodiversity, encompassing more than 50,000 cultivated varieties that display substantial variation in fruit morphology, color, and pungency intensity (Antonio et al., 2018). Among the domesticated *Capsicum* species, *C. annuum* exhibits the greatest morphological and genetic diversity, characterized by extensive variation in fruit size, shape, and coloration (Hill et al., 2013). It shares close morphological and genetic similarity with *C. chinense* and *C. frutescens*, collectively referred to as the *C. annuum* complex (Gonzalez-Perez et al., 2014). Morphologically, *C. annuum* is an annual herbaceous plant adapted to warm climates and well-drained soil, where it shows optimal vegetative growth and reproductive performance (Murillo-Amador et al., 2015). The plant typically reaches a height of 0.6－1.0 m and produces simple, alternate leaves along with solitary or occasionally clustered white flowers emerging from the leaf axils (Oh and Koh, 2019; Barboza et al., 2022). The fruit, a true berry, exhibits wide morphological diversity, ranging from elongated or conical to round or blocky forms (Barboza et al., 2022). Fruit color varies among cultivars and ripening stages, from white, yellow, and orange to red, and occasionally to deep purple or brown (Li et al., 2022). *P. nigrum* L., commonly known as black pepper, belongs to the genus *Piper* within the family Piperaceae, which comprises more than 1,400 tropical species distributed worldwide (Salehi et al., 2019). The genus includes several economically important species, notably *P. nigrum* L., *P. longum* L., and *P. betle* L., among which *P. nigrum* L. is the most extensively cultivated and commercially significant (Ravindran, 2000). *P. nigrum* has been reported to originate from the Western Ghats of India, particularly in the Kerala region, where it has been cultivated for millennia as one of the earliest domesticated spice crops (Wimalarathna et al., 2024). The genus *Piper* displays high biodiversity across tropical regions, encompassing numerous wild and cultivated species that differ markedly in morphology, reproductive characteristics, and secondary metabolite composition (Salehi et al., 2019). Within the genus, *P. nigrum* exhibits pronounced intraspecific variation in growth form, leaf morphology, spike length, and fruit traits, reflecting natural diversity and long-term domestication (Reshma et al., 2022). *P. nigrum* is a perennial woody climber adapted to warm and humid tropical conditions (Indu et al., 2022). It grows best in partially shaded environments supported by trees or poles, with glabrous stems that can extend beyond 10 m in height (Ashokkumar et al., 2021). The vine exhibits a dimorphic branching pattern, consisting of orthotropic shoots responsible for vertical growth and plagiotropic branches that produce flowers and fruits (Chandy and Pillay, 1979), which form the characteristic architecture of *P. nigrum* in natural and cultivated habitats.

2. Forms of Supplementation

Phytogenic feed additives derived from *C. annuum* L. and *P. nigrum* L. are commonly incorporated into poultry diets in various supplemental forms, including plants, essential oils, and purified bioactive compounds. These forms differ considerably in their physiochemical stability, concentration of active constituents, and overall biological activity (Abd El-Hack et al., 2022; Ogbuewu et al., 2023). Feed additives derived from *C. annuum* are typically supplied as powder, solvent-based extracts, and oleoresin concentrates enriched with capsaicinoids and carotenoids (Gutiérrez-Chávez et al., 2025). Among these, oleoresin is the most widely utilized form, characterized by a standardized mixture of capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homodihydrocapsaicin, and homocapsaicin, which collectively determines its distinctive pungency and physiological functionality (Sharma et al., 2021). Similarly, *P. nigrum* L. derived feed additives are available as powder, solvent-based extracts, and purified crystalline piperine, depending on the desired chemical purity and extraction procedure (Chopra et al., 2016). Recent advancements in feed processing technologies have facilitated the development of microencapsulated and nanoemulsified phytogenic systems designed to protect thermolabile compounds such as capsaicin and piperine from oxidative and thermal degradation. These delivery systems markedly improve intestinal stability, enhance bioavailability, and ensure a more consistent physiological response in poultry (Abdelli et al., 2021; Soussi et al., 2025).

PHYTOCHEMICAL COMPOSITION AND MECHANISM

1. Major bioactive Compounds in *Capsicum annuum* L.

C. annuum is recognized for its high nutritional value and represents a major dietary source of bioactive compounds, particularly capsaicinoids, carotenoids, flavonoids, and vitamins C and E, which collectively contribute to its functional and physiological significance (Villa-Rivera and Ochoa-Alejo, 2020). Capsaicinoids, the principal alkaloids responsible for the characteristic pungency of *C. annuum*, exhibit potent antioxidant and anti-inflammatory activities that underline their physiological functionality (Alonso-Villegas et al., 2023). Carotenoids are lipophilic pigments with strong antioxidant properties that contribute to immune modulation and tissue protection (Tan et al., 2014; Palma et al., 2020). The physiological benefits of chili pepper derived bioactive compounds are primarily attributed to their antioxidant capacity and regulatory functions, which mitigate oxidative stress and modulate immune responses (Erin and Szallasi, 2023; Zhang et al., 2024). Therefore, this review highlights the physiological roles of the major bioactive compounds, particularly carotenoids and capsaicinoids, and explores their potential as functional feed additives in poultry diets. Carotenoids are naturally occurring pigments responsible for red, yellow, and orange coloration in nature and are predominantly present in the fruits and leaves of plants (Bartley and Scolnik, 1995). Most carotenoids consist of 40 carbon atoms and possess conjugated double bonds within their molecular structure (Rodrguez-Concepcion et al., 2018). Based on their chemical characteristics, carotenoids are classified into primary and secondary types, with the primary forms functioning in association with chlorophyll as essential photosynthetic pigments (Zulfiqar et al., 2021). Representative carotenoids include α-carotene, β-carotene, and lycopene (Fraser et al., 2004). Among the diverse carotenoids, β-carotene and lycopene have been extensively characterized due to their potent antioxidant activities and physiological relevance in poultry (Çalışlar, 2019; Chen et al., 2023). β-carotene serves as a provitamin A compound and exhibits strong antioxidant capacity by efficiently quenching singlet oxygen and other reactive oxygen species (ROS), thereby protecting cellular membranes from lipid peroxidation and oxidative damage (Grune et al., 2010). Lycopene, a non-provitamin A carotenoid, also possesses remarkable antioxidant potential due to its long chain of conjugated double bonds, which facilitates efficient neutralization of free radicals and ROS (Long et al., 2024). Capsaicinoids are bioactive secondary metabolites belonging to the alkaloid group, and they are uniquely present in the chili pepper fruits (Islam et al., 2023). These compounds are concentrated mainly in the placental and interlocular septal tissues of the fruits, where they play an important role in maintaining the physiological functions of the plant (Delgado-Vargas et al., 2000). Capsaicin and dihydrocapsaicin are the predominant capsaicinoids and represent the major bioactive components responsible for the characteristic pungency of chili peppers (Delgado-Vargas et al., 2000; Giuffrida et al., 2013). Minor capsaicinoids, including nordihydrocapsaicin, homodihydrocapsaicin, and homocapsaicin, are present in trace amounts (Giuffrida et al., 2013). Capsaicin is the most abundant bioactive compound in chili peppers and exhibits diverse physiological effects, including anti-inflammatory, antioxidant, and metabolic regulatory (Panchal et al., 2018). Its antioxidant and anti-inflammatory effects are primarily associated with the reduction of oxidative cellular damage by inhibiting glutathione oxidation induced by ROS (Kim and Lee, 2014). Moreover, capsaicin and dihydrocapsaicin modulate inflammatory responses by suppressing the production of pro-inflammatory cytokines in immune cells such as macrophages (Thongin et al., 2022). In terms of metabolic regulation, capsaicin has been reported to increase energy expenditure and suppress appetite through the activation of the transient receptor potential vanilloid 1 (TRPV1) receptor (Ludy et al., 2012). These physiological effects are primarily mediated through TRPV1-mediated signaling, which serves as a principal mechanism of action (Fattori et al., 2016). The physiological responses to capsaicin are primarily based on the modulation of intracellular signaling pathways through TRPV1, a non-selective cation channel involved in thermoregulation, nociception, and metabolic control (Frias and Merighi, 2016). Upon binding to this receptor, capsaicin induces calcium influx into the cell, thereby triggering a cascade of downstream signaling pathways (Rosenbaum et al., 2004). Regarding gastrointestinal regulation, capsaicin enhances digestive function by stimulating visceral sensory neurons through TRPV1 activation, which promotes the secretion of cholecystokinin (CCK), and facilitates intestinal motility and digestive enzyme secretion (Yamamoto et al., 2003). In terms of lipid metabolism, capsaicin has been reported to upregulate hepatic cholesterol 7 alpha-hydroxylase expression, thereby promoting bile acid synthesis and consequently reducing circulating cholesterol levels (Zhang et al., 2013). In addition, capsaicin exerts antioxidant effects by reducing ROS generation and enhancing the activities of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), thereby effectively alleviating oxidative stress (Li et al., 2023).

2. Major Bioactive Compounds in *Piper nigrum* L.

P. nigrum L., widely recognized for its medicinal and nutritional significance, serves as important spice rich in diverse bioactive constituents. Phytochemical investigations have identified a wide range of secondary metabolites in *P. nigrum*, including alkaloids, tannins, saponins, terpenes, steroids, and flavonoids such as catechin and myricetin, with piperine being the predominant pungent alkaloid (Ogbuewu and Mbajiorgu, 2023). These compounds collectively contribute to the characteristic aroma, flavor, and therapeutic properties of the plant (Damanhouri and Ahmad, 2014). Within the alkaloid group of *P. nigrum*, piperine, piperetine, chavicine, and piperidine have been identified as the major constituents, with piperine representing the most abundant and biologically active compound (Siddiqui et al., 2023). The piperine content of *P. nigrum* typically varies from 1.7 to 7.4%, depending on the cultivar, maturity stage, and environmental growing conditions (Tripathi et al., 2022). In addition to the alkaloid fraction, *P. nigrum* contains essential oils that contribute to its characteristic aroma and exhibit a wide range of biological activities (Dosoky et al., 2019).

These volatile oils, which are rich in nerolidol and other terpenoids, are characterized by potent antioxidant, antimicrobial, and anti-inflammatory activities (Ashokkumar et al., 2021). *P. nigrum* contains enzymatic antioxidants such as glutathione peroxidase and glucose-6-phosphate dehydrogenase, which contribute to enhanced antioxidant defense and immune modulation in animals (Abou-Elkhair et al., 2014). Phenolic compounds in *P. nigrum* L. contribute substantially to its antioxidant capacity by promoting free radical scavenging (Wang et al., 2021). In addition to these non-volatile phenolics, *P. nigrum* also contains volatile essential oils with highly variable yields. The yield of essential oils in *P. nigrum* exhibits considerable variation depending on the plant variety, developmental stage, anatomical source, and extraction method, with reported values ranging from 0.69 to 1.76% in spike and 0.29 to 0.44% in stem (Feitosa et al., 2024). Despite this wide variability, the essential oils of *P. nigrum* remain highly concentrated sources of bioactive compounds with antioxidant and metabolic-regulatory activities (Diniz do Nascimento et al., 2020; Mahmoud et al., 2022). Furthermore, piperine, the predominant alkaloid, plays a central role in digestive and metabolic actions of *P. nigrum* (Srinivasan, 2007). It promotes the secretion of pancreatic enzymes and bile acids, thereby facilitating more efficient nutrient digestion, absorption, and utilization (Hasanthi et al., 2023). Piperine has been reported to suppress hepatic xenobiotic-metabolizing enzymes, altering gastrointestinal transit dynamics, collectively contributing to improved metabolic efficiency (Sehgal et al., 2013; Capasso et al., 2022).

EFFECTS OF DIETARY SUPPLEMENTATION WITH *CAPSICUM ANNUUM* L. AND *PIPER NIGRUM* L. IN POULTRY

1. Growth and Productive Performance

Previous studies examining the effect of dietary supplementation with *C. annuum* L. and *P. nigrum* L. in different forms on growth and productive performance in poultry are summarized (Tables 1, 2, and 3). Regarding the powder form of *C. annuum* L. and *P. nigrum* L., dietary supplementation of red pepper at 2.5, 5.0, 7.5, and 10 g/kg improved body weight gain (BWG) and feed intake (FI) in broiler chickens (Al-Kassie et al., 2011). Dietary supplementation with 0.2 g/kg red pepper showed improved body weight (BW), FI, and feed conversion ratio (FCR) in broiler chickens (Shahverdi et al., 2013). Supplementation of chili pepper at 0.5 and 1.0 g/kg increased BW in broiler chickens (Marić et al., 2021). Regarding *P. nigrum* L., dietary supplementation of black pepper at 2 g/kg improved BW, FI, and FCR in broiler chickens (Shahverdi et al., 2013). Broiler chickens fed diets containing 5, 10, and 15 g/kg black pepper showed improved BWG and FCR than those fed diets without black pepper (Singh et al., 2019). In terms of extracts from *C. annuum* L. and *P. nigrum* L., dietary supplementation with natural *Capsicum* extract at 0.8 g/kg increased BWG in broiler chickens (Liu et al., 2021b). Broiler chickens fed diets containing 0.25, 0.5, and 1 mL/kg hot red pepper oil showed improved BWG, FI, and FCR (Hassan and El-Ktany, 2020). Furthermore, dietary supplementation of red pepper oil at 0.4, 0.8, 1.2, and 1.6 g/kg increased BWG and FI in Japanese quails (Reda et al., 2020). Laying hens fed diets containing 5 g/kg black pepper oil had greater egg weight, egg mass, and egg production than those fed diets without black pepper oil (Samantaray and Nayak, 2022). Supplementation of black pepper oil at 0.4, 0.8, 1.2, and 1.6 g/kg improved BWG and FCR in Japanese quails (Reda et al., 2024). Regarding the bioactive compounds from *C. annuum* L. and *P. nigrum* L., dietary supplementation with capsaicin at 0.02, 0.04, and 0.06 g/kg improved FCR in broiler chickens (Li et al., 2022). Ducks fed diets containing 0.15 g/kg capsaicin showed increased FI. Additionally, supplementation with capsaicinoid at 0.25 and 0.50 g/kg increased FI and egg production in Japanese quails (Sahin et al., 2017). Along with *P. nigrum* L., broiler chickens fed diets containing 0.2, 0.4, 0.6, and 0.8 g/kg micellar piperine showed improved BW and BWG (Ahammad and Kim, 2025). Dietary supplementation with piperine at 0.6, 1.2, and 1.8 g/kg improved BWG and FCR in broiler chickens (Cardoso et al., 2012). Therefore, these findings indicate that dietary supplementation with *C. annuum* L. and *P. nigrum* L. in various processed forms may effectively improve growth and productive performance in poultry, although the magnitude of the response depends on the processing form and inclusion level of the ingredients. Collectively, the growth-promoting

Table 1. Effects of dietary supplementation with powders from *Capsicum annuum* and *Piper nigrum* in poultry[1]

Animals	Feed additive	Inclusion level	Optimal inclusion level	Positive effects[2]	References
Broiler chicken	Hot red pepper	0, 2.5, 5.0, 7.5, 10 g/kg	10 g/kg	Growth performance (BWG↑, FI↑), serum parameter (cholesterol↓), blood parameter (H:L ratio↓), jejunal morphology (VH↑, VW↑)	Al-Kassie et al. (2011)
	Red pepper	0, 0.2 g/kg	0.2 g/kg	Growth performance (BW↑, FI↑, FCR↓), serum parameter (TG↓, cholesterol↓), blood parameter (H:L ratio↓)	Shahverdi et al. (2013)
	Hot red pepper	0, 5.0, 10 g/kg	5.0 g/kg	Growth performance (BW↑), serum parameter (TG↓, TC↓, LDL↓, HDL↑)	Puvača et al. (2015)
	Hot red pepper	0, 2.5, 5.0, 7.5, 10 g/kg	5.0 g/kg	Growth performance (FE↑), serum parameter (TG↓, cholesterol↓, LDL↓, HDL↑)	Munglang and Vidyarthi (2020)
	Chili pepper	0, 0.5, 1.0 g/kg	500 g/kg	Growth performance (BW↑), serum parameter (TG↓, TC↓, LDL↓, HDL↑)	Marić et al. (2021)
	Red pepper	0, 0.2 g/kg	0.2 g/kg	Growth performance (BW↑)	Acharya et al. (2025)
Broiler chicken	Black pepper	0, 2.0 g/kg	2.0 g/kg	Growth performance (BW↑, FI↑, FCR↓), serum parameter (TG↓, cholesterol↓), blood parameter (H:L ratio↓)	Shahverdi et al. (2013)
	Black pepper	0, 5.0, 10 g/kg	10 g/kg	Serum parameter (TG↓, TC↓, LDL↓, HDL↑)	Puvača et al. (2015)
	Black pepper	0, 2 g/kg	2 g/kg	Growth performance (BWG↑, FI↑, FCR↓), serum parameter (TG↓, cholesterol↓, HDL↑, LDL↓)	Rahimian et al. (2016)
	Black pepper	0, 5, 10, 15 g/kg	5 g/kg	Growth performance (BWG↑, FCR↓), serum parameter (TG↓, cholesterol↓), duodenal morphology (VH↑, CD↓, VH:CD↑)	Singh et al. (2019)
	Black pepper	0, 0.2 g/kg	0.2 g/kg	Growth performance (BW↑)	Acharya et al. (2025)
Japanese quail	Black pepper	0, 5.0 g/kg	5.0 g/kg	Serum parameter (cholesterol↓), ileal morphology (VH↑)	Ashayerizadeh et al. (2023)

[1] BWG, body weight gain; H:L ratio, heterophil to lymphocyte ratio; VH, villus height, VW, villus width; FCR, feed conversion ratio; TG, triglyceride; FE, feed efficiency; LDL, low-density lipoprotein; HDL, high-density lipoprotein; BW, body weight; TC, total cholesterol; CD, crypt depth.

[2] The symbol '↑' represented an increase, while '↓' denoted a decrease.

effects of *C. annuum* L. appear to be associated with enhanced digestive function and the metabolic actions of capsaicinoids (Yamamoto et al., 2003), whereas improvements observed with *P. nigrum* L. supplementation are likely attributed to stimulated digestive enzyme secretion (Hasanthi et al., 2023).

2. Blood Parameter

Studies have reported the effects of different processed forms of *C. annuum* L. and *P. nigrum* L. on blood parameters in poultry (Tables 1, 2, and 3). In the case of the powder form of *C. annuum* L. and *P. nigrum* L., dietary supplementation with hot red pepper at 2.5, 5.0, 7.5, and 10 g/kg decreased heterophil to lymphocyte (H:L) ratio in the blood of broiler chickens (Al-Kassie et al., 2011). Dietary inclusion of red pepper at 0.2 g/kg decreased triglyceride (TG), cholesterol in the serum and H:L ratio in the blood of broiler chickens (Shahverdi et al., 2013). Furthermore, broiler chickens fed diets containing 2.5, 5.0, 7.5, and 10 g/kg showed improved TG, cholesterol, low-density lipoprotein

Table 2. Effects of dietary supplementation with extracts from *Capsicum annuum* and *Piper nigrum* in poultry[1]

Animals	Feed additive	Inclusion level	Optimal inclusion level	Positive effects[2]	References
Broiler chicken	Red pepper seed oil meal	0, 5, 10 g/kg	10 g/kg	Serum parameter (TC↓)	An et al. (2007)
	Hot red pepper oil	0, 0.25, 0.5, 1 mL/kg	0.5 mL/kg	Growth performance (BWG↑, FI↑, FCR↓),	Hassan and El-Ktany (2020)
	Natural *Capsicum* extract	0, 0.8 g/kg	0.8 g/kg	Growth performance (BWG↑), digestive enzyme activity in the pancreas (trypsin↑, lipase↑), serum parameter (LDL↓, TC↓, GH↑), antioxidant capacity in the serum (TAC↑, GSH-Px↑, SOD↑)	Liu et al. (2021b)
	Hot red pepper oil	0, 0.25, 0.50, 1.00 mL/kg	0.50 mL/kg	Serum parameter (TG↓, cholesterol↓, LDL↓)	Hassan et al. (2023)
Japanese quail	Red pepper oil	0, 0.4, 0.8, 1.2, 1.6 g/kg	0.8 g/kg	Growth performance (BWG↑, FI↑, FCR↓), serum parameter (TG↓, TC↓, HDL↑), antioxidant capacity (MDA↓, CAT↑, GSH↑)	Reda et al. (2020)
Broiler chicken	Black pepper oil	0, 0.002 g/mL	0, 0.002 g/mL	Growth performance (BWG↑, FI↑, FCR↓), serum parameter (TG↓, cholesterol↓, LDL↓, HDL↑)	Ghaedi et al. (2013)
	Black pepper oil	0, 0.25, 0.5 g/kg	0.5 g/kg	Growth performance (BWG↑, FCR↓), serum parameter (TC↓, LDL↓, HDL↑)	Kishawy et al. (2022)
Laying hen	Black pepper oil	0, 5 g/kg	5 g/kg	Productive performance (EW↑, egg mass↑, EP↑), serum parameter (cholesterol↓, LDL↓, HDL↑)	Samantaray and Nayak (2022)
Japanese quail	Black pepper oil	0, 0.4, 0.8, 1.2, 1.6 g/kg	1.6 g/kg	Growth performance (BWG↑, FCR↓), serum parameter (TG↓, TC↓, LDL↓, HDL↑), antioxidant capacity in the plasma (SOD↑, CAT↑, GSH↑, MDA↓)	Reda et al. (2024)

[1] BWG, body weight gain; LDL, low-density lipoprotein; TC, total cholesterol; GH, growth hormone; TAC, total antioxidant capacity; GSH-Px, glutathione peroxidase; SOD, superoxide dismutase; FI, feed intake; FCR, feed conversion ratio; TG, triglyceride; HDL, high-density lipoprotein; MDA, malondialdehyde; CAT, catalase; GSH, glutathione; EW, egg weight; EP, egg production.
[2] The symbol '↑' represented an increase, while '↓' denoted a decrease.

(LDL), and high- density lipoprotein (HDL) in the serum (Munglang and Vidyarthi, 2020). With respect to *P. nigrum* L., dietary supplementation with black pepper at 0.2 g/kg decreased TG and cholesterol in the serum in broiler chickens (Shahverdi et al., 2013). Dietary inclusion of black pepper at 5 g/kg decreased cholesterol in the serum of Japanese quails (Ashayerizadeh et al., 2018). Regarding extracts from *C. annuum* L. and *P. nigrum* L., dietary supplementation with hot red pepper oil at 0.25, 0.50, and 1.00 mL/kg decreased TG, cholesterol, and LDL in the serum of broiler chickens (Hassan et al., 2023). Supplementation with red pepper oil at 0.4, 0.8, 1.2, and 1.6 g/kg improved TG, TC, and HDL in the serum of Japanese quails (Reda et al., 2020). For *P. nigrum* L., Japanese quails fed diets containing 0.4, 0.8, 1.2, and 1.6 g/kg black pepper oil showed improved TG, TC, and HDL and decreased LDL in the serum (Reda et al., 2024). Therefore, current findings indicate that *C. annuum* L. and *P. nigrum* L., when provided in various processed forms, may beneficially modulate blood lipid profiles and stress-related biomarkers in poultry. Therefore, the beneficial effects of *C. annuum* L. on blood parameters appear to be associated with the hypolipidemic and antioxidant actions of capsaicinoids (Zhang et al., 2013; Li et al., 2023), including the reduction of cholesterol and TG and the attenuation of stress responses reflected by lower H:L ratio. In contrast, improvements attributed to *P. nigrum* L. are likely driven by the lipid-lowering, which contributes to reductions in circulating lipids in serum lipoprotein profiles (Hasanthi et al., 2023).

Table 3. Effects of dietary supplementation with bioactive compounds from *Capsicum annuum* and *Piper nigrum* in poultry[1]

Animals	Feed additive	Inclusion level	Optimal inclusion level	Positive effects[2]	References
Japanese quail	Capsaicinoid	0, 0.25, 0.50 g/kg	0.50 g/kg	Productive performance under HS conditions (FI↑, EP↑), antioxidant capacity in the ovary under HS conditions (MDA↓, SOD↑, CAT↑, GSH-Px↑)	Sahin et al. (2017)
Duck	Capsaicin	0, 0.15 g/kg	0.15 g/kg	Productive performance (FI↑), antioxidant capacity in the ovary (MDA↓)	Liu et al. (2021a)
Broiler chicken	Capsaicin	0, 0.02, 0.04, 0.06 g/kg	0.04 g/kg	Growth performance (FCR↓), digestive enzyme activity (trypsin↑)	Li et al. (2022)
Turkey	Capsaicin	0, 0.4, 0.8 g/kg	0.8 g/kg	Growth performance (FCR↓), antioxidant capacity in the serum (ROS↓)	Zanotto et al. (2023)
Laying hen	Capsaicin	0, 0.12, 0.24, 0.36 g/kg	0.36 g/kg	Antioxidant capacity in the serum (SOD↑, GSH-Px↑, TAC↑, MDA↓), digestive enzyme activity in the duodenum (Amylase↑, lipase↑, trypsin↑), antioxidant capacity in the liver (SOD↑, GSH-Px↑, MDA↓)	Zhang et al. (2025)
Broiler chicken	Piperine	0, 0.6, 1.2, 1.8 g/kg	0.6 g/kg	Growth performance (BWG↑, FCR↓), duodenal morphology (VW↑, CD↓), ileal morphology (VH↑, VW↑)	Cardoso et al. (2012)
	Piperine	0, 0.6 g/kg	0.6 g/kg	Growth performance (BWG↑, FCR↓)	Trindade et al. (2019)
	Micellar piperine	0, 0.2, 0.4, 0.6, 0.8 g/kg	0.8 g/kg	Growth performance (BW↑, BWG↑)	Ahammad and Kim (2025)

[1] FCR, feed conversion ratio; SOD, superoxide dismutase, GSH-Px, glutathione peroxidase; TAC, total antioxidant capacity; MDA, malondialdehyde; FI, feed intake; ROS, reactive oxidative stress; EP, egg production; CAT, catalase; BW, body weight; BWG, body weight gain; VW, villus width; CD, crypt depth; VH, villus height.
[2] The symbol '↑' represented an increase, while '↓' denoted a decrease.

3. Antioxidant Capacity

Previous studies have extensively examined the effects of different processed forms of *C. annuum* L. and *P. nigrum* L. on antioxidant capacity in poultry (Tables 1, 2, and 3). Regarding the extracts from *C. annuum* L. and *P. nigrum* L., dietary supplementation with natural *Capsicum* extract at 0.8 g/kg increased glutathione peroxidase (GSH-Px), superoxide dismutase (SOD), and total antioxidant capacity (TAC) in the serum of broiler chickens (Liu et al., 2021b). Japanese quails fed diets containing 0.4, 0.8, 1.2, and 1.6 g/kg showed improved catalase (CAT), and glutathione (GSH) and decreased malondialdehyde (MDA) in the serum (Reda et al., 2020). Dietary inclusion of black pepper oil at 0.4, 0.8, 1.2, and 1.6 g/kg improved SOD, CAT, and GSH and decreased MDA in the plasma of Japanese quails (Reda et al., 2024). Regarding the bioactive compounds from *C. annuum* L., dietary supplementation with capsaicin at 0.12, 0.24, and 0.36 g/kg improved SOD, GSH-Px, and TAC and decreased MDA in the liver of laying hens (Zhang et al., 2025). Inclusion of capsaicinoid at 0.25 and 0.50 g/kg in diets improved SOD, CAT, and GSH-Px and decreased MDA in the ovaries of Japanese quails raised under heat stress conditions (Sahin et al., 2017). Collectively, the antioxidant-enhancing effects of *C. annuum* L. appear to be largely attributed to the potent free radical-scavenging properties of capsaicinoids and carotenoids, which upregulate endogenous antioxidant enzymes and mitigate oxidative stress (Li et al., 2023). In contrast, the antioxidant responses induced by *P. nigrum* L. are likely mediated through the actions of piperine and associated phenolic constituents, which promote antioxidant defenses in poultry (Abou-Elkhair et al., 2014).

4. Gut Health and Digestive Enzyme Activity

Previous studies examining the effects of different dietary forms of C. annuum L. and P. nigrum L. on gut health and digestive enzyme activity in poultry are summarized (Tables 1, 2, and 3). Concerning the powder form of *C. annuum* L. and *P. nigrum* L., inclusion of hot red pepper at 2.5, 5.0, 7.5, and 10 g/kg in diets increased villus height (VH) and villus width (VW) in the jejunum of broiler chickens (Al-Kassie et al., 2011). Dietary supplementation with black pepper at 5, 10, and 15 g/kg increased VH and VH:CD and decreased crypt depth (CD) in the duodenum of broiler chickens (Singh et al., 2019). Furthermore, Japanese quails fed diets containing black pepper at 5 g/kg had greater VH in the ileum than those fed diets without black pepper (Ashayerizadeh et al., 2023). In terms of extracts from *C. annuum* L., dietary supplementation with natural *Capsicum* extract at 0.8 g/kg increased trypsin and lipase activities in the pancreas of broiler chickens (Liu et al., 2021b). Regarding bioactive compounds from *C. annuum* L., broiler chickens fed diets containing capsaicin at 0.02, 0.04, and 0.06 g/kg showed increased trypsin in the pancreas (Li et al., 2022). Dietary inclusion of capsaicin at 0.12, 0.24, and 0.36 g/kg increased amylase, lipase, and trypsin activities in the duodenum of laying hens (Zhang et al., 2025). For *P. nigrum* L., dietary supplementation with piperine at 0.6, 1.2, and 1.8 g/kg increased VH and VW in the ileum of broiler chickens (Cardoso et al., 2012). Overall, the gut-enhancing effects of *C. annuum* L. appear to be associated with capsaicinoid-mediated stimulation of digestive secretions, improved intestinal morphology that support nutrient digestion (Yamamoto et al., 2003; Al-Kassie et al., 2011). In contrast, the intestinal benefits associated with *P. nigrum* L. are primarily attributable to piperine-mediated improvements in intestinal morphology, including enhanced villus height and width, which support more efficient nutrient absorption (Singh et al., 2019).

CONCLUSION

C. annuum L. and *P. nigrum* L. contain diverse bioactive compounds that exert a wide range of beneficial physiological effects in poultry. Evidence across studies indicates that powders, solvent extracts, oleoresins, oils, and purified bioactive constituents from these plants may enhance growth performance, modulate blood lipid profiles and stress biomarker, strengthen antioxidant capacity, and improve intestinal morphology and digestive enzyme activity. Notably, improvements in digestive enzyme activity are more consistently associated with capsaicinoid-rich *C. annuum* L., whereas enhancements in antioxidant capacity are more prominent with piperine from *P. nigrum* L. Nevertheless, considerable variability exists in their efficacy depending on processing methods, phytochemical composition, dosage, and bioavailability. These factors should be carefully considered when selecting supplemental forms and inclusion levels for practical dietary applications.

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