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Review Article

Harnessing *Curcuma* Rhizome to Combat Climate Stress in Poultry: Mechanistic Insights, Emerging Applications, and Opportunities for Sustainable Rural Poultry Farming

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Abstract

Climate stress significantly affects poultry productivity, welfare, and immune competence, especially in rural and low-input production systems. Increasing interest in phytogenic feed additives has highlighted *Curcuma* rhizome powder as a promising natural supplement due to its antioxidant, anti-inflammatory, and immunomodulatory properties. Curcumin, the principal bioactive compound of *Curcuma* rhizome, has been reported to improve growth performance, immune response, antioxidant enzyme activity, and physiological stability in poultry exposed to environmental stress. Several studies demonstrate that dietary turmeric or curcumin supplementation improves feed efficiency, reduces oxidative stress markers, and enhances productivity in broilers and laying hens under heat stress conditions.

This review summarizes the mechanisms, experimental evidence, and practical application potential of *Curcuma* spp. rhizome supplementation for mitigating climate stress in poultry production systems. It also highlights the bioavailability challenges and dosage optimization. Improving bioavailability, determining optimal inclusion levels, and evaluating cost-effectiveness for rural poultry production remain key research priorities for integrating curcuma supplementation into climate-resilient poultry production strategies.

Keywords: Curcumin; Phytogenic Feed Additives; Rural Poultry; Oxidative Stress; Climate Resilience

Introduction

Poultry production plays a critical role in global food security and rural livelihoods. At the same time, productivity is highly sensitive to environmental stressors, particularly temperature extremes associated with climate variability. Heat stress is one of the most significant challenges affecting poultry production, as it disrupts physiological homeostasis, impairs immune function, reduces feed intake, and decreases growth performance [1]. One of the primary mechanisms underlying heat stress–induced damage is the excessive generation of reactive oxygen species (ROS), which leads to oxidative stress and cellular damage [2–4]. Elevated ROS levels result in lipid peroxidation, tissue damage, and impairment of the endogenous antioxidant defense system, including enzymes such as catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GPx) [4,5]. Similarly, cold stress alters metabolic processes, endocrine regulation, and immune responses in poultry. Birds exposed to cold conditions exhibit increased metabolic demands to maintain body temperature, resulting in higher energy expenditure, altered nutrient utilization, and increased susceptibility to disease [4,6,7]. To mitigate these challenges, nutritional strategies have been widely explored. Dietary supplementation with vitamins, minerals, amino acids, fatty acids, polyphenols, and phytogenic compounds has shown promising potential in alleviating the adverse effects of thermal stress in poultry [8]. Among these approaches, plant-derived phytogenic feed additives are gaining increasing attention as sustainable alternatives to antibiotic growth promoters due to their multifunctional biological activities. These compounds can enhance nutrient utilization, improve feed efficiency, and reduce disease incidence in poultry production systems [9]. Turmeric (*Curcuma longa*) rhizome contains several bioactive compounds, including curcuminoids, essential oils, and phenolic compounds with potent antioxidant, anti-inflammatory, and immunomodulatory properties. Curcumin, the principal active compound, has been shown to improve growth performance, antioxidant status, and immune responses in heat-stressed broilers and laying hens [10,11]. With the increasing frequency of extreme climatic events and their detrimental effects on poultry health, metabolism, and productivity, phytogenic feed additives have emerged as promising tools for enhancing resilience in poultry production systems. Therefore, this review aims to evaluate the effectiveness and feasibility of *Curcuma* spp. supplementation in mitigating oxidative stress, improving immune stability, and enhancing growth and gut health in poultry under climate stress conditions.

Impact of climate on poultry and effects of curcuma on climate stressed Poultry

Climate stress, particularly heat stress, significantly impairs poultry productivity and welfare, necessitating effective nutritional mitigation strategies. Exposure to high ambient temperatures disrupts thermoregulation, reduces feed intake, impairs nutrient metabolism, and increases oxidative stress in birds. Herbal feed supplements have been identified as potential natural thermoregulatory agents capable of reducing the adverse effects of heat stress in poultry [3,8]. Cold stress also represents a major challenge in poultry production, especially in rural and backyard production systems where environmental control is limited. Low ambient temperatures increase maintenance energy requirements, elevate metabolic stress, and suppress immune function [6,8]. Experimental studies have demonstrated that early-life exposure to cold stress negatively affects digestive organ development, immune function, and overall performance in broilers [12]. Rural poultry production systems are particularly vulnerable to climate stress because of limited access to temperature-controlled housing, inconsistent feed quality, and restricted veterinary support. In such systems, low-cost herbal supplements are attractive due to their availability, affordability, and minimal risk of chemical residues. Recent studies have reported that curcumin nanoparticles improve growth performance, antioxidant status, intestinal architecture, and immune responses in heat-stressed broilers [13,14]. Curcumin supplementation has also been shown to regulate lipid metabolism, enhance antioxidant defense systems, and reduce the negative effects of heat stress on production performance [15,16]. For instance, dietary supplementation with turmeric rhizome powder (0.4–0.8%) improved feed efficiency in heat-stressed broilers [17]. Other studies have reported improvements in immune indices, physiological parameters, intestinal morphology, and microbial balance in birds supplemented with turmeric powder or extract [18,19].

Bioactive compounds and biological activities in *Curcuma* spp

The Curcuma plant is a rhizomatous herbaceous perennial plant belonging to the *Zingiberaceae* family. It is native to tropical Asia, with roughly 80 known species characterized by its aromatic, fleshy rhizomes and prominent bracts. The three commonly found *Curcuma* spp found in the north eastern region of India are *Curcuma longa*, which is mostly cultivated; *Curcuma caesia*, which is partly cultivated; and Curcuma *angustifolia*, which grows in the wild.

Curcuma longa (Indian turmeric)

Curcuma longa is considered as functional foods and commonly known as Indian turmeric use as spice in colouring and flavouring cuisines. Turmeric rhizome typically contains carbohydrates (69.4%), protein (6.3%), fat (5.1%), and minerals (3.5%) [20]. Turmeric rhizomes are known to contain a wide range of bioactive compounds responsible for their pharmacological and nutritional properties. These compounds include *curcuminoids*, essential oils, phenolic compounds, peptides, and various mineral elements. Among these constituents, curcuminoids are considered the primary active compounds, including curcumin, demethoxycurcumin (DMC) and bis-demethoxycurcumin (BDMC) [11]. It also contains essential oils such as turmerone, atlantone, curlone, terpinolene, germacrone, zingiberene [21]. Studies have also identified multiple volatile and non-volatile molecules including peptides and mineral elements which include iron, potassium, sodium, calcium, magnesium, and phosphorus [22], all contributing to anti-inflammatory, anti-oxidant, anti-microbial, and other pharmacological and immunomodulatory functions.

Figure 1: *Curcuma longa* –(a) Rhizome, (b) cut section of rhizome, (c) aerial view showing vegetative stage of *Curcuma* cultivation.

Curcumin has been widely studied for its therapeutic potential and it has been reported to have a variety of biological activities. It acts as a reactive oxygen species scavenger and inhibits lipid peroxidation, thereby protecting tissues from oxidative damage [6,10,12]. Curcuminoids are also known to modulate NF-κB signalling and immune response pathways [15]. Under heat stressed conditions, multiple studies showed using of turmeric powder or extract as feed supplement improved immune indices, physiological parameters and blood lipid profile in poultry. Heat-stressed broilers with curcumin supplementation at 1g/kg diet, improved growth, immune markers, thyroid hormones, and antioxidant enzymes while reducing cholesterol, triglycerides, and oxidative stress markers [21]. It improved production performance, intestinal morphology, and microbial balance in broilers [18,19] and reduced the negative impacts of heat stress by regulating lipid metabolism and antioxidant defence [14,15]. In laying hens, curcuma supplementation improved egg quality [11] and reproductive health by enhancing gene expression related to reproductive performance [23].

Curcuma caesia (Black turmeric)

Belonging to the family of Zingiberaceae, *Curcuma caesia*, commonly known as black turmeric has gained significant scientific interest for its potent therapeutic properties. It is rich in bioactive compounds including flavonoids, phenols, tannins [24], a rich source of elements such as sodium, calcium, potassium, magnesium, phosphorous and iron [25] and other compounds like curcuminoids, camphor, germacrane, curcumenol, ar-turmerone, zederon and elemane, suggesting antioxidant, anti-inflammatory, antifungal, antimicrobial potential [22,25]. It is also known to be rich in curcumin and bismethoxycurcumin [26], the compounds widely studied for its beneficial effects in poultry production. Community and ethnobotanical discussions also note that black turmeric is used medicinally in traditional systems to treat asthma, bruises, cough, dysentery, diarrhoea, indigestion, jaundice, piles, leukoderma, epilepsy, tonsillitis, diabetes, boils, scabies, hepatic disorders, rheumatism, antiseptic, bleeding, wound healing and inflamed mucous membranes [27–29]. It aids in acid reflux, enhances absorption and smoothen the function of liver and kidney. It is also known to help in treating snake bite and scorpion sting [29].

Figure 2: *Curcuma caesia* –(a) Rhizome, (b) cut section of rhizome, (c) vegetative stage of *Curcuma* cultivation.

Curcuma angustifolia (East Indian arrowroot)

Curcuma angustifolia commonly known as East Indian arrowroot, has been reported to be a rich source of starch which is commonly used as a nutritional aid for gastrointestinal issues; and other secondary metabolites such as curcumin, alkaloids, phenols, terpenoids, saponins [22], essential oils (Curzerenone,14-hydroxy-δ-cadinene, γ-eudesmol acetate, camphor, and germacrone) which contribute to the pharmacological functions in poultry production such as anti-inflammatory, anti-microbial, anti-ulcerogenic, anti-oxidant, anti-fungal and anti-bacterial [22,30]. It is traditionally used for gut health and gastrointestinal disorders. The use of rhizome paste has been documented in treatment of leprosy, leukoderma, burning sensations, and to stop bleeding in cattle injured by leeches; decoction is used to treat asthma, dyspepsia, dysentery, jaundice, anaemia, kidney stones [22,28].

Figure 3: *Curcuma angustifolia* –(a) Rhizome, (b) cut section of rhizome, (c) and (d) flowers in its natural habitat.

Anti-oxidant and anti-inflammatory effects of Curcumin on climate stressed poultry

Curcumin exhibits a significant anti-inflammatory effect in poultry. Its supplementation enhances endogenous antioxidant enzymes such as SOD, CAT, GPx and TAC. Simultaneously, it scavenges free radicals and reduces malondialdehyde, a marker of oxidative stress. This reduces oxidative damage during heat and cold stress [4,5,31]. Climate stress induces ROS, damaging cellular structures, wherein antioxidants help neutralize them [13,32]. Curcumin reduces heat-induced oxidative damage, improves cellular protection and gene expression related to immune and antioxidant pathways in broilers exposed to toxins or stressors [11,33]. It regulates cytokine expression, enhances macrophage function [15], and improves antibody production [23] thereby enhancing cytokine expression and immune organ function, improving disease resistance [34]. Turmeric supplementation increases immunoglobulins [11], complement proteins and anti-inflammatory cytokines and reduces pro-inflammatory markers like IL-1β, IL-6 and IFN-γ in heat-stressed broilers [33,35]. It improves growth performance, enhances immunity and reduce inflammation by downregulating pro-inflammatory cytokines such as IL-2, IL-6 and TNF-a [36,37] while supporting anti-inflammatory cytokines like IL-10, reducing stress-induced inflammation. Curcumin also inhibits NF-κB signalling pathway which is a key regulator of inflammation [12,14]. Nutritional interventions are essential to reduce productivity losses under climate stress conditions. Cold-stress-induced immune dysregulation may be countered via antioxidant signalling pathways, while heat-stress-suppressed immunity, caused by oxidative damage to immune cells, may be restored through antioxidant supplementation.

Beneficial effects of Curcumin supplementation

Studies shows curcumin supplementation improves body weight gain, feed conversion ratio, carcass quality [11]. In laying hens, supplementation at 150 mg/kg improves egg production, shell quality and antioxidant enzyme activity [38], at 200mg/kg enhances nutrient absorption which improves overall growth performances under heat-stressed conditions [18], repairs or reduces the damage in liver, spleen, intestine, bursa and muscle tissues cause by heat stressed [21]. It promotes the development of pectoral muscle [36] and activates the antioxidant defence mechanism of liver [37]. Other studies have shown that curcumin reduces injury in liver and heart tissue [15]. Curcumin-derived phytogenic feed supplementation supports intestinal health, improved beneficial gut microbiota such as Actinobacteria and Bacteroidetes, while also boosting enzyme secretion leading to better absorption and immune defense [33]. It reduces intestinal inflammation induced by lipopolysaccharide (LPS) through modulating gut microbiota and regulating bile acid metabolism, which in turn enhance mucosal immunity [23,42]. Moreover, curcumin nanoparticles beneficially modulated caecal microbiota by enhancing lactic acid bacteria and reducing pathogenic bacteria [43].

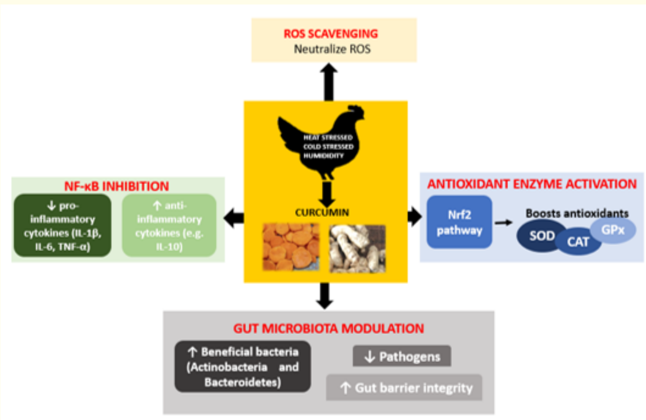

Figure 4: Mechanisms of Curcumin in climate stress mitigation.

Feeding dosage and dose recommendations in poultry

Based on published studies, typical recommended inclusion levels for poultry range from 0.5-2% for turmeric rhizome powder and 50-300 mg/kg feed for curcumin extract [11], depending on species, stress level, and production stage. Studies report that inclusion of 200 mg/kg curcumin showed significantly lower caecal lesion during stress [34]. Other studies showed 200 mg/kg and 300 mg/kg curcumin significantly improve intestinal function in laying hens [35].

Species	Stress type	Dose/form	Major findings	Reference
Broilers and laying hens	Heat	Curcumin extract	Improved growth performance, antioxidant status, and immune responses	[10,11]
Broilers	Heat	0.4–0.8% rhizome powder	Improved feed efficiency	[17]
Laying hens	Heat	150 mg/kg rhizome powder	Improved egg production and shell quality	[11,38]
Laying hens	Heat	200 mg/kg rhizome powder	Enhanced nutrient absorption	[18]
Broilers and laying hens	Heat	Curcumin extract	Reduced damage organs	[19]
Broiler	Infection stress	Curcumin extract	Improved gut health	[33]

Table 1: Summarization of studies in *Curcuma* spp to mitigate stress conditions in poultry.

Advantages of supplementation

Incorporation of turmeric as a dietary supplement in poultry has gained increasing attention as a natural and safe phytogenic feed additive. It exhibits multifunctional effects, including strong antioxidant, ant-inflammatory, immune and gut microbiota modulation, enhances growth and productivity [11]. Such effects are beneficial for birds under climate stress conditions, where conventional feeding strategies often fail to ensure productivity and health. Additionally, with rising concerns of antibiotics over the potential of microbial resistance and leaving residues, phytogenic feed additives like turmeric has been shown to be potential alternatives to antibiotics due to their anti-microbial, anti-oxidant and metabolic enhancing effects [10,42]. Since Curcuma *spp* are locally available and cost-effective, therefore, this makes it especially suitable for smallholder and backyard poultry farmer as they often rely on locally sourced feed ingredients and herbal additives.

Limitations and research gaps

Despite multiple studies showed interest in using turmeric as a phytogenic feed additive in poultry, several other limitations and research gaps remain. The poor bioavailability of curcumin is one of the primary challenges, mainly due to its hydrophobic nature, it exhibits poor water solubility, poor chemical instability [45] and low intestinal absorption [46]. Although techniques like encapsulation and nanoparticulate formulation have been explored for increasing the solubility and bioavailability; their production and preparation is challenging [45,47]. Moreover, lack of standardization in turmeric processing and dosage; and insufficient long-term field studies, limit clear interpretation and practical recommendations. There are also very limited direct poultry feeding trials specifically evaluating the use of *Curcuma caesia* or *Curcuma angustifolia*; therefore, much of the current understanding is drawn from studies on *Curcuma longa*-based phytogenic feed additives, broader plant extract applications in poultry nutrition, and evidence from ethnoveterinary and herbal livestock feeding practices. Furthermore, most studies have focused on heat stress conditions, whereas evidence on cold stress conditions remains limited, constraining its relevance across varying climates.

Thus, future research should prioritize the use of technological tools for the development and evaluation of cost-effective curcumin target delivery systems to enhance bioavailability, stability and to integrate their application in commercial poultry farming; and conducting dose optimization studies across different environmental climate stress, across different poultry species, and different age groups.

Conclusion

Curcuma spp represents a promising phytogenic feed additive for mitigating climate-induced stress in poultry production. Its bioactive compound curcumin enhances antioxidant defense systems, modulates immune responses, improves gut health, and supports growth performance under thermal stress conditions. Advances in delivery technologies may further enhance its bioavailability and efficacy. With increasing climate variability affecting poultry production worldwide, Curcuma supplementation could play an important role in developing sustainable and climate-resilient poultry production systems, particularly in rural and smallholder farming environments.

Bibliography

1. Ramshon U., *et al*. "Climate-Resilient Poultry Feeding in Integrated Farming Systems of Northeast India". *Asian Journal of Research in Animal and Veterinary Sciences* 8.3 (2025): 421-427.
2. Ncho CM., *et al*. "Abiotic stressors in poultry production: A comprehensive review". *Journal of Animal Physiology and Animal Nutrition* 109.1 (2025): 30-50.
3. Olayiwola SF and Adedokun SA. "Heat stress in poultry: the role of nutritional supplements in alleviating heat stress and enhancing gut health in poultry". *Frontiers in Veterinary Science* 12 (2025): 1691532.
4. Aminullah N., *et al*. "Phytogenic feed additives as alternatives to antibiotics in poultry production: A review". *Veterinary World* 18.1 (2025): 141-154.
5. Oni AI., *et al*. "The role of phytogenic feed additives in stress mitigation in broiler chickens". *Journal of Animal Physiology and Animal Nutrition* 108.1 (2024): 81-98.
6. Abo-Al-Ela HG., *et al*. "Stress and immunity in poultry: light management and nanotechnology as effective immune enhancers to fight stress". *Cell Stress Chaperones* 26.3 (2021): 457-472.
7. Li D., *et al*. "Physiological Responses of Laying Hens to Chronic Cold Stress and Ammonia Exposure: Implications for Environmental Management and Poultry Welfare". *Animals* 15.12 (2025): 1769.
8. Sahib QS., *et al*. "Mitigating Cold Stress in Livestock by Nutritional Interventions: A Comprehensive Review". *Indian Journal of Animal Research* 58.3 (2024): 353-363.
9. Ipcak HH and Denli M. "The potential of herbal feed additives in poultry nutrition". *CABI Review* 19.1 (2024).
10. El-Saadony MT., *et al*. "Curcumin, an active component of turmeric: biological activities, nutritional aspects, immunological, bioavailability, and human health benefits - a comprehensive review". *Frontiers in Immunology* 16 (2025): 1603018.
11. Zhang J., *et al*. "Curcumin, a plant polyphenol with multiple physiological functions of improving antioxidation, anti-inflammation, immunomodulation and its application in poultry production". *Journal of Animal Physiology and Animal Nutrition* 108 (6 (2024): 1890-905.

12. Moreira LM., *et al*. "Effects of cold stress on physiologic metabolism in the initial phase and performance of broiler rearing". *Journal of Thermal Biology* 119 (2024): 103773.

13. Abdel-Moneim AME., *et al*. "Dietary incorporation of biological curcumin nanoparticles improved growth performance, ileal architecture, antioxidative status, serum lipid profile, and humoral immune response of heat-stressed broiler chickens". *Poultry Science* 104.2 (2025): 104740.

14. Fathi M., *et al*. "Impact of curcumin nanoparticles supplementation on antioxidant status, growth performance, immune function, gut microbiota, and hematobiochemical parameters in heat-stressed broiler chickens". *Italian Journal of Animal Science* 24.1 (2025): 2109-2118.

15. Geevarghese AV., *et al*. "Curcumin and curcumin nanoparticles counteract the biological and managemental stressors in poultry production: An updated review". *Research in Veterinary Science* 162 (2023): 104958.

16. He Z., *et al*. "Curcumin and selenium synergistically mitigate oxidative stress in white-feathered broilers". *Frontiers in Veterinary Science* 12 (2025): 1600466.

17. Kichu M., *et al*. "Influence of Turmeric Based Diet on the Performance of Broiler Chicken". *Asian Journal of Animal Sciences* 17.1 (2023): 21-30.

18. Rajput N., *et al*. "Effect of dietary supplementation of curcumin on growth performance, intestinal morphology and nutrients utilization of broiler chicks". *Journal of Poultry Science* 50 (1 (2013): 44-52.

19. Urban J., *et al*. "Enhancing broiler chicken health and performance: the impact of phytobiotics on growth, gut microbiota, antioxidants, and immunity". *Phytochemistry Review* 24.2 (2025): 2131-2145.

20. Jasim SA., *et al*. "The Beneficial Application of Turmeric (Curcuma longa L.) on Health and Egg Production, in Layers: A Review". *Veterinary Medical Science* 10.6 (2024): e70115.

21. Dosoky NS., *et al*. "Variations in the Volatile Compositions of Curcuma Species". *Foods* 8.2 (2019): 53.

22. Rajkumari S and Sanatombi K. "Nutritional value, phytochemical composition, and biological activities of edible Curcuma species: A review". *International Journal of Food Properties* 20 (2017): S2668-87.

23. Sureshbabu A., *et al*. "The impact of curcumin on livestock and poultry animal's performance and management of insect pests". *Frontiers in Veterinary Science* 10 (2023): 1048067.

24. Gangal A., *et al*. "Chemical composition, in vitro antioxidant and α-amylase inhibitory activities of rhizomes essential oil and nutrient components from rhizomes powder of Curcuma caesia Roxb. (black turmeric) collected from Garhwal region of Uttarakhand, India". *Journal of Essential Oil Bearing Plants* 26.6 (2023): 1473-1486.

25. Paudel A., *et al*. "Pharmacological insights into Curcuma caesia Roxb., the black turmeric: a review of bioactive compounds and medicinal applications". *Discovery Plants* 1.1 (2024): 69.

26. Desai M., *et al*. "Targeted modulation of MMP9 and GRP78 via molecular interaction and in silico profiling of Curcuma caesia rhizome metabolites: A computational drug discovery approach for cancer therapy". *PLOS One* 20.7 (2025): e0328509.

27. Udayani W., *et al*. "Antioxidant Activity of Ethanol and Methanol Extracts of Black Turmeric (Curcuma Caesia Roxb.) Using the DPPH (2,2-Diphenyl-1-Picrylhidrazyl) Method". *Scientific Midwifery* 10.5 (2022): 4342-4349.

28. Sharma GJ., *et al*. "Gingers of Manipur: diversity and potentials as bioresources". *Genetic Resources and Crop Evolution* 58.5 (2011): 753-767.

29. Jyotirmayee B., *et al*. "The impact of organic fertilizers on Growth, Yield, and rhizospheric bacterial diversity in black turmeric (Curcuma caesia)". *Journal of Angiotherapy* 8.5 (2024).

30. Jena S., *et al*. "Chemical composition and antioxidant activity of essential oil from leaves and rhizomes of Curcuma angustifolia Roxb". *Natural Product Research* 31.18 (2017): 2188-2191.

31. Abd El-Hack ME., *et al*. "Herbs as thermoregulatory agents in poultry: An overview". *Science of the Total Environment* 703 (2020): 134399.

32. Arya OP., *et al*. "Health-promoting bioactive phenolic compounds in different solvent extracts of Curcuma caesia Roxb. rhizome from North-East India". *Journal of Food Processing and Preservation* 46.8 (2022).

33. Ogwuegbu MC and Mthiyane DMN. "Molecular antioxidant and immunological mechanisms of phytogenics in the mitigation of aflatoxicosis in poultry". *Journal of Applied Poultry Research* 33.3 (2024): 100457.

34. Yadav S., *et al*. "The effects of different doses of curcumin compound on growth performance, antioxidant status, and gut health of broiler chickens challenged with Eimeria species". *Poultry Science* 99.11 (2020): 5936-5945.

35. Xu Z., *et al*. "Supplementation of curcumin promotes the intestinal structure, immune barrier function and cecal microbiota composition of laying hens in early laying period". *Poultry Science* 103.12 (2024): 104355.

36. Eleiwa NZ., *et al*. "Dietary Curcumin Modulating Effect on Performance, Antioxidant Status, and Immune-Related Response of Broiler Chickens Exposed to Imidacloprid Insecticide". *Animals* 13.23 (2023): 3650.

37. Hafez MH., *et al*. "The Impact of Curcumin on Growth Performance, Growth-Related Gene Expression, Oxidative Stress, and Immunological Biomarkers in Broiler Chickens at Different Stocking Densities". *Animals* 12.8 (2022): 958.

38. Liu M., *et al*. "Effect of curcumin on laying performance, egg quality, endocrine hormones, and immune activity in heat-stressed hens". *Poultry Science* 99.4 (2020): 2196-202.

39. Gharib HSA., *et al*. "Using curcumin (Curcuma longa) as a dietary supplement modulates performance, behavior, blood metabolites, antioxidant status, and histomorphological changes in heat-stressed broiler chickens". *Journal of Thermal Biology* 130 (2025): 104144.

40. Bai D., *et al*. "Curcumin alleviates the effects of heat stress on broiler pectoral muscle via decorin (DCN) -mediated TGF-β Signaling pathway". *Poultry Science* 105.2 (2026): 106231.

41. Zhang JF., *et al*. "Curcumin attenuates heat-stress-induced oxidant damage by simultaneous activation of GSH-related antioxidant enzymes and Nrf2-mediated phase II detoxifying enzyme systems in broiler chickens". *Poultry Science* 97.4 (2018): 1209-1219.

42. Ruan D., *et al*. "Curcumin alleviates LPS-induced intestinal homeostatic imbalance through reshaping gut microbiota structure and regulating group 3 innate lymphoid cells in chickens". *Food Function* 13.22 (2022): 11811-11824.

43. Moniei F., *et al*. "Effect of different levels of turmeric (Curcuma longa) on productivity in broiler chickens". *Journal of the Hellenic Veterinary Medical Society* 75.3 (2024): 7801-7814.

44. Rahman SU., *et al*. "Curcumin mitigates Cryptosporidium parvum infection through modulation of gut microbiota and innate immune-related genes in immunosuppressed neonatal mice". *Microbe Pathogen* 164 (2022): 105424.

45. Jiang T., *et al*. "Recent advances in encapsulation of curcumin in nanoemulsions: A review of encapsulation technologies, bio accessibility and applications". *Food Research International* 132 (2020): 109035.

46. Shaikh J., *et al*. "Nanoparticle encapsulation improves oral bioavailability of curcumin by at least 9-fold when compared to curcumin administered with piperine as absorption enhancer". *European Journal of Pharmaceutical Sciences* 37.3-4 (2009): 223-230.

47. Chen Y., *et al*. "Nano Encapsulated Curcumin: And Its Potential for Biomedical Applications". *International Journal of Nanomedicine* 15 (2020): 3099-3120.