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The Beneficial Application of Turmeric (*Curcuma longa* L.) on Health and Egg Production, in Layers: A Review

Saade Abdalkareem Jasim[1] | Aiman Mohammed Baqir Al-Dhalimy[2] | Maryam Zokaei[3,4] | Shadi Salimi[5] | Mohammed Jawad Alnajar[6] | Abhinav Kumar[7,8,9] | Enas R. Alwaily[10] | Ahmed Hussein Zwamel[11] | Soura Alaa Hussein[12] | Majid Gholami-Ahangaran[13]

[1]Medical Laboratory Techniques Department, College of Health and Medical Technology, Al-Maarif University, Anbar, Iraq | [2]Department of Nursing, Altoosi University College, Najaf, Iraq | [3]Department of Food Science and Technology, Faculty of Nutrition Science, Food Science and Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Science, Tehran, Iran | [4]Department of Food Science and Technology, School of Agriculture, Shiraz University, Shiraz, Iran | [5]Department of Food Science and Technology, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran | [6]Anesthesia techniques, Al-Nisour University College, Baghdad, Iraq | [7]Department of Nuclear and Renewable Energy, Ural Federal University Named after the First President of Russia Boris Yeltsin, Ekaterinburg, Russia | [8]Department of Technical Sciences, Western Caspian University, Baku, Azerbaijan | [9]Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore, India | [10]Microbiology Research Group, College of Pharmacy, Al-Ayen University, Thi-Qar, Iraq | [11]Department of Medical Laboratory Technology, College of Medical Technology, The Islamic University, Najaf, Iraq | [12]Department of Medical Laboratory Technologies, Al Rafidain University College, Baghdad, Iraq | [13]Department of Clinical Sciences, Faculty of Veterinary Medicine, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran

Correspondence: Majid Gholami-Ahangaran (mgholami6@gmail.com)

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ABSTRACT

Background: Turmeric (*Curcuma longa* L.) is a widely recognized spice and medicinal plant that has gained significant attention for its potential health benefits. This review aims to provide a comprehensive overview of the beneficial applications of turmeric in improving health and egg production in layers.

Objective: The objective of this review is to assess the current scientific literature on the effects of turmeric supplementation in layer diets and evaluate its impact on layer health and egg production.

Methods: A systematic search was conducted in Google Scholar database to identify relevant studies published in peer-reviewed journals. Studies investigating the effects of turmeric or its bioactive compound curcumin on layer health and egg production were included. Data on various parameters, including immune function, reproductive performance, egg quality and production parameters, were extracted and analysed.

Results: Turmeric contains a bioactive compound called curcumin, which possesses antioxidant, anti-inflammatory, antimicrobial and immunomodulatory effects. These properties have been extensively studied and have shown promising results in enhancing layer health and performance. Turmeric supplementation has been reported to improve the overall immune response in layers, reducing the incidence and severity of infectious diseases. It has also been shown to have positive effects on gut health by modulating the gut microbiota composition, improving nutrient absorption and reducing digestive disorders. Furthermore, studies have demonstrated that turmeric supplementation in layer diets can improve egg weight, shell quality, yolk colour and egg production rates. The mechanisms underlying these effects involve the antioxidant properties of turmeric, which protect the reproductive organs, enhance ovarian function and improve reproductive performance.

Conclusion: The findings underscore the potential of turmeric as a natural, cost-effective and sustainable intervention for improving layer well-being, egg quality and productivity. However, further research is needed to fully understand the mechanisms of action, optimize dosage regimens and evaluate the long-term effects of turmeric supplementation in layer diets.

1 | Introduction

Poultry nutrition experts were particularly interested in investigating natural alternatives to antibiotics that could be used in poultry feed. The goal was to reduce the competitive effectiveness of bacterial resistance and minimize residual traces in poultry products (Gholami-Ahangaran, Moravvej, et al. 2021). In recent years, natural medicinal products derived from herbs have been explored as additives in animal feed, including for farm animals (Guo 2003). These plant-based products are considered advantageous compared to synthetic antibiotics or inorganic chemicals because they are natural, less toxic and do not leave behind residues. Consequently, they are seen as ideal additives for animal feed in food production (R. Wang, Li, and Bourne 1998).

Medicinal plants and herbs have a long history of being used to address various health issues in poultry. Their nutritional and immunological effects have been recognized, ranging from improved feed efficiency to the regulation of endogenous digestive enzymes. Additionally, these plants have shown immune response stimulation, antiviral, antibacterial and antioxidant properties, making them highly valuable (Gholami-Ahangaran, Karimi-Dehkordi, et al. 2021). In poultry production, the primary objective is to achieve enhanced performance by improving feed efficiency while ensuring the safety of the final products for consumption (Bahmani et al. 2014; Gholami-Ahangaran, Peimani, and Ahmadi-Dastgerdi 2019).

Turmeric, scientifically known as *Curcuma longa*, is among the various phytogenic additives that hold significance in the production of poultry feed (Olarotimi 2018). According to Linnaeus' classification, turmeric belongs to the taxonomic group order Zingiberales, family Zingiberaceae, class Liliopsida, subclass Commelinids, genus *Curcuma* and species *Curcuma longa*, commonly referred to as turmeric (Khulel 2023). The medicinal use of turmeric primarily focuses on the rhizome, which is used for human remedies, as well as non-medicinal purposes like food seasoning or feed additives (Dono 2014). Turmeric is native to tropical South Asia and thrives in temperatures ranging between 20°C and 30°C (Khan et al. 2012).

Numerous studies have highlighted the beneficial effects of turmeric on laying hens. For instance, the supplementation of layer diets with 5 g/kg of turmeric meal has been reported to increase the percentage of hen day production (%HDP). Moreover, when hens were fed a diet containing 10 g/kg of turmeric meal, there was a significant improvement in internal and external egg qualities, including egg weight, egg mass, yolk weight and yolk index (Radwan Nadia et al. 2008). The researchers further suggested that turmeric may have a positive effect on the calcium deposition site in the oviduct, thereby increasing shell weight and thickness.

However, several other studies have presented contrasting findings regarding the beneficial effects of turmeric that were previously highlighted. For instance, Moorthy et al. (2009) found no significant impact on laying birds and the percentage of hen day egg production when 0.1% turmeric was included in the diet of Single Comb White Leghorn layers. Similarly, Riasi, Kermanshahi, and Fathi (2008) reported that feeding laying hens with various levels of turmeric (ranging from 0.0 to 2.0 g/kg of feed) had no significant effect on specific gravity, egg shell thickness, egg shell weight and the ratio of egg shell weight to egg weight. Furthermore, Malekizadeh, Moeini, and Ghazi (2012) supported these findings by demonstrating that supplementing the diet of single-comb White Leghorn (W-36) laying hens with 10.0 or 30.0 g/kg of turmeric meal did not influence egg production, egg weight or egg mass. The dissimilarities observed in these studies regarding egg traits may be attributed to variations in the experimental methods employed or possibly due to the dosage of turmeric used, suggesting a potential dose-dependent issue.

The study aimed to investigate later studies related to the beneficial effect of turmeric on egg indices and production, growth and performance, and other biological parameters in layer chickens.

2 | Nutritional Benefits of Turmeric

Several researchers have provided information on the proximate composition of turmeric rhizome. According to Chattopadhyay et al. (2004), turmeric contains approximately 6.3% protein, 5.1% fat, 3.5% minerals, 69.4% carbohydrates and 13.1% moisture. However, Ikpeama, Onwuka, and Nwankwo (2014) reported higher values for these components (Table 1).

TABLE 1 | Proximate composition of turmeric plant.

Parameters	Compositions (%)
Moisture	8.9
Dry matter	91
Ash	2.85
Crude fibre	4.60
Crude protein	9.4
Fat	6.85
Carbohydrate	67.38

TABLE 2 | The composition of amino acid in isolated protein of turmeric.

Essential amino acids		Non-essential amino acids	
Amino acid	**Content (%)**	**Amino acid**	**Content (%)**
Ariginine	2.48	Alanine 2.55	2.25
Histidine	1.80	Aspartic acid 5.05	5.05
Isoleucine	7.58	Glutamic acid 8.75	8.75
Leucine	2.53	Glycine 3.42	3.42
Lysine	12.73	Serine 2.29	2.29
Methionine	3.28	Tyrosine 3.68	3.68
Threonine	2.87		
Valine	1.53		

The amino acid composition of protein isolates is an important indicator of their nutritional value. Table 2 presents the concentrations of essential and non-essential amino acids in the isolated protein (Das et al. 2014). The protein isolate was found to contain 9 essential amino acids and 7 non-essential amino acids, out of the total 16 amino acids. These findings indicate that the isolated protein is a complete protein. Among the essential amino acids, lysine was found to be present in the highest quantity, whereas glutamic acid was the most abundant non-essential amino acid in the isolated protein (Das et al. 2014).

Turmeric is recognized for its rich content of minerals and vitamins. In a study conducted by Ikpeama, Onwuka, and Nwankwo (2014), it was found that turmeric contains approximately 0.16% thiamine, 0.59% riboflavin, 2.30% niacin, 0.20% calcium, 0.63% phosphorus, 0.46% potassium and 0.05% iron.

The steam distillation of turmeric rhizome yields approximately 5.8% essential oil. This essential oil consists of various components, including 1% α-phellandrene, 1% cineol, 0.6% sabinene, 25% zingiberene, 1% borneol and 53% sesquiterpenes (Sotiboldieva and Mahkamov 2020).

Curcumin, the major active compound found in turmeric, has been reported to possess various nutritional and antioxidant properties. Curcumin powder derived from turmeric is known to be a rich source of minerals such as calcium, phosphorus, potassium and magnesium, as well as total phenols, flavonoids and vitamin C (Youssef et al. 2014).

Furthermore, research has indicated that turmeric can stimulate the digestive system and increase the secretion of intestinal lipases, amylase, trypsin and chymotrypsin enzymes, thereby enhancing digestibility (Rajput et al. 2012).

The detailed information on the nutritional values and antioxidant contents of curcumin is manifested in Table 3 as reported by Youssef et al. (2014).

TABLE 3 | Chemical characterization of curcumin powder.

Index	Ingredient	Value
Chemical composition (%)	Moisture	6.60
	Ash	9.67
	Protein	9.34
	Fat	2.46
	Fibre	4.02
	Total carbohydrates	67.91
	Caloric value (kcal/100 g)	331.10
Mineral content (mg/kg)	Mn	23
	Cu	6
	Fe	110
	Ca	2288
	Mg	1795
	P	5439
	Na	947
	K	5513
Antioxidant contents g/100 g)	Total phenols	6.487
	Flavonoids	4.509
	Lycopene	0.0173
	Vitamin C	2.59
	Vitamin E	0.31
Fatty acids content (g/100 g)	14-Pentadecenoic acid	0.2
	22-Tricosenoic acid	0.1
	Hexacosanoic acid	0.4
	Hexadecanedioic acid	0.1
	6-Octadecenoic acid	0.2
	Octadecenoic acid	0.2
	Linoleic acid	0.9
	Oleic acid	0.7
	Palamitic acid	0.1
	Stearic acid	0.1
	Total fatty acids	3
Essential amino acids (g/100 g)	Isoleucine	0.01
	Leucine	0.04
	Lysine	0.08
	Methionine	0.01
	Phenylalanine	0.202
	Threonine	0.04
	Tryptophan	0.01
	Valine	0.01
	Total essential amino acids	0.203

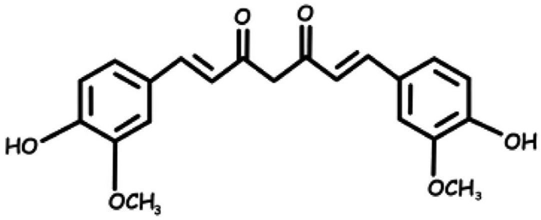

FIGURE 1 | Chemical structure of curcumin.

3 | Active Ingredients of Turmeric

The active components of turmeric rhizomes are classified into volatile and non-volatile constituents. The non-volatile constituents, which are responsible for the coloration of turmeric, primarily include phenolic compounds such as curcumin (Dono, 2014). Other important non-volatile active substances found in turmeric are demethoxycurcumin, bisdemethoxycurcumin and colourless metabolites like tetrahydrocurcumin (Huang et al. 1995).

On the other hand, the volatile oil of turmeric contains various active substances. The major active compounds in the volatile oil include curcuminoids (Toennesen 1992), ar-turmerone (L. A. Ferreira et al. 1992), zingiberene (Smith and Robinson 1981), turmerone (Baik, Jung, and Ahn 1993) and curlone (Kiso et al. 1983). These volatile constituents contribute to the aroma and flavour of turmeric.

Curcumin, also known as diferuloylmethane, is a crystalline yellow-orange colour, with molecular weight of 368.39 g/mol, and the chemical formula $C_{21}H_{20}O_6$ (Figure 1; Amalraj et al. 2017).

Curcumin is a polyphenolic compound and the natural yellow pigment found in the roots of turmeric (*Curcuma longa*). It is obtained by isolating it from the rhizomes of the plant. Curcumin is characterized as an oily soluble crystalline powder with a melting point of 174°C (Sogi et al. 2010). Approximately 2%–5% of turmeric is composed of curcumin, accounting for around 4% of the extract's dry weight (Agarwal et al. 2001).

Curcumin is renowned for its diverse range of biological activities. It exhibits antioxidant, antibacterial, antifungal, antiprotozoal, antiviral, anti-inflammatory, anticarcinogenic, antihypertensive and hypocholesteric properties (Khan et al. 2012). Additionally, curcumin and curcuminoids possess antinematicidal, anti-inflammatory, antioxidative, anticoccidial and immunomodulatory effects (Dono 2014).

The biological properties of curcumin and other phytochemicals have been extensively studied. For instance, curcumin demonstrates antibacterial, antiviral, antioxidant, anti-inflammatory and antitumour activities, while arturmerone exhibits antisnakebite properties. Furthermore, methyl curcumin has been found to possess antibacterial and antiprotozoal effects against *Leishmania amazonensis*, and *curcuminoids* have shown antiprotozoal activity against *Plasmodium falciparum* and *Leishmania major* (Araújo and Leon, 2001).

4 | Biological Activity of Turmeric

The compounds present in turmeric have been extensively studied for their biological activities. Some of the notable activities associated with these compounds are:

4.1 | Antioxidant Properties

Curcuminoids, including curcumin, exhibit potent antioxidant activity both in vitro and in vivo. The antioxidant properties of curcumin are attributed to the presence of phenolic groups in its molecular structure. This antioxidant activity is closely linked to the anti-inflammatory, hepatoprotective and cardioprotective effects of curcumin. Curcumin has been shown to effectively combat oxidative stress and its associated damage (Srinivasan 2014).

Studies have demonstrated that curcumin can be used in combination with drug therapy for oxidative stress-related diseases, enhancing the antioxidant defence system and providing additional protection against oxidative damage (Amalraj et al. 2017).

In the context of poultry production, Radwan Nadia et al. (2008) found that including 0.5% of turmeric (*Curcuma longa* L.) in the feed of chickens can improve their productive performance. Additionally, the inclusion of turmeric benefits the oxidative stability of eggs and reduces the oxidation of yolk lipids during storage. This suggests that turmeric's antioxidant properties contribute to the preservation of egg quality and the reduction of lipid oxidation.

Overall, curcuminoids, particularly curcumin, possess powerful antioxidant activity, which has implications for various aspects of health, including anti-inflammatory effects, protection against oxidative stress-related diseases and preservation of food quality.

4.2 | Anti-Inflammatory Property

Curcumin's action against inflammation involves multiple molecular pathways, making it a versatile anti-inflammatory agent. It exerts its effects by reducing immune response, enhancing xenobiotic metabolism, ameliorating inflammation by decreasing neutrophil migration and improving barrier remodelling (Liczbiński, Michałowicz, and Bukowska 2020).

Curcumin interacts with numerous molecular targets involved in inflammation, as highlighted by Jurenka (2009). One of the mechanisms by which curcumin exerts its anti-inflammatory effects is through the inhibition of inflammatory cytokines. In in vitro studies, curcumin has been shown to regulate the activation of activating protein-1 (AP-1) and nuclear factor kappa B (NF-κB) in stimulated monocytes and alveolar macrophages. By doing so, curcumin blocks the expression of genes encoding cytokines, thereby reducing the production of inflammatory mediators (Jobin et al. 1999).

In addition to its effects on cytokines, curcumin has been demonstrated to inhibit arachidonic acid metabolism and inflammation in mouse skin epidermis through the down-regulation of the cyclooxygenase and lipoxygenase pathways, as shown in in vivo studies (Huang et al. 1991). These pathways are involved in the production of pro-inflammatory mediators, such as prostaglandins and leukotrienes (Abdulkhaleq et al. 2018; Boroumand, Samarghandian, and Hashemy 2018).

Overall, curcumin's anti-inflammatory action involves modulation of the immune response, regulation of inflammatory cytokines, inhibition of arachidonic acid metabolism and modulation of signalling pathways such as AP-1 and NF-κB. These mechanisms contribute to curcumin's ability to suppress inflammation and hold promise for its therapeutic potential in inflammatory conditions.

4.3 | Antimicrobial Activity

In the study conducted by Chen et al. (2010), the activity of curcumin against influenza viruses was evaluated. The researchers found that curcumin disrupts the virus–cell interactions, thereby hindering the multiplication of the influenza virus. Curcumin was also found to have a direct effect on the infectivity of viral particles. These findings suggest that curcumin has the potential to inhibit the replication and spread of influenza viruses (L. L. C. Ferreira et al. 2022).

Zhang et al. (2012) investigated the action of curcuminoids on the growth of *Candida albicans* using microcalorimetry. The study revealed that the presence of a methoxy group in curcuminoids enhances the lipophilicity of the compound's core structure. This increased lipophilicity facilitates the entry of the molecule into the cell membrane of fungi, thereby inhibiting the growth of *Candida albicans*. The structural activity relationship analysis supported the notion that the methoxy group contributes to the antifungal activity of curcuminoids.

Furthermore, Mirbod et al. (2017) observed an interesting effect of turmeric supplementation in farmed laying hens. They found that turmeric supplementation led to a decrease in the counts of *Escherichia coli* (*E. coli*) in the ileal content of the hens. This suggests that turmeric supplementation may have antimicrobial effects against *E. coli* in the gastrointestinal tract of the birds.

These studies highlight the potential of curcumin and turmeric in combating viral infections, inhibiting fungal growth and exerting antimicrobial effects. The findings support the use of curcumin and turmeric in various applications, including the development of antiviral and antifungal therapies, as well as the promotion of gut health in poultry farming.

4.4 | Immunomodulatory Properties

The polar fraction of *Curcuma longa* (turmeric) has been found to possess inhibitory effects on the proliferation of cancer cells. This suggests that the components present in the polar fraction, such as curcuminoids and polysaccharides, could potentially serve as adjuvant supplements for cancer patients whose immune systems have been suppressed by chemotherapy (Al-Saidy et al., 2021). The study conducted by Yue et al. (2010a) supports the notion that curcuminoids and polysaccharides derived from turmeric may have beneficial effects in supporting the immune system and inhibiting cancer cell growth.

In addition to the polar fraction, specific compounds found in turmeric, such as α-turmerone and ar-turmerone, have shown stimulatory effects on the proliferation of peripheral blood mononuclear cells (PBMCs) and the production of cytokines. PBMCs play a crucial role in the immune response by producing various cytokines that regulate immune activity (Del Prete et al. 2016). The study conducted by Yue et al. (2010b) suggests that α-turmerone and ar-turmerone, present in turmeric, have the potential to enhance immune function by promoting PBMC proliferation and cytokine production.

These findings indicate that certain components of turmeric, including curcuminoids, polysaccharides, α-turmerone and ar-turmerone may have immunomodulatory properties and could be beneficial as adjuvant supplements for cancer patients undergoing chemotherapy or in supporting overall immune health. However, further research is needed to fully understand the mechanisms of action and potential therapeutic applications of these compounds (Raje et al. 2015).

5 | The Effect of Turmeric on Growth Performance in Layers

Radwan Nadia et al. (2008) found that laying hens fed turmeric-supplemented diets showed a 1% increase in feed intake compared to those on non-supplemented diets. This suggests that turmeric supplementation may enhance the palatability of the feed, potentially due to its special aroma.

Furthermore, D. Wang et al. (2016) reported that turmeric-supplemented diets in laying hens resulted in increased levels of enzymes such as amylase, trypsin, chymotrypsin and lipase. These enzymes are involved in the digestion and metabolism of nutrients. The improved enzyme activity suggests that turmeric supplementation may positively influence feed conversion ratio (FCR), which is a measure of how efficiently animals convert feed into body weight.

Regarding broilers, D. Wang et al. (2016) observed that the daily feed intake increased with the addition of 100 and 200 mg/kg of turmeric rhizome extract, but decreased with the addition of 300 mg/kg. These findings are consistent with the results of Moeini, Malekizadeh, and Ghazi (2011) and Malekizadeh, Moeini, and Ghazi (2012), where the inclusion of 3% turmeric rhizome powder in the laying hen diet led to a decrease in daily feed intake.

In a study by Lagana et al. (2011), the addition of 2% turmeric rhizome powder to the laying hen diet resulted in a reduction in both feed intake and FCR.

Riasi, Kermanshahi, and Mahdavi (2012) discovered that supplementing layers' diet with 1.5 and 2 g/kg of turmeric powder for 4 weeks during the second production cycle at 100 weeks of age resulted in a significant decrease in feed intake. The group receiving 2 g/kg of turmeric powder showed a significant improvement in feed conversion compared to the groups that

TABLE 4 | The effect of turmeric on growth performance in layers.

Layer breed	Age	Duration of experiment	Source	Doses	Results	References
Al-Salaam	28–40 weeks	12 weeks	TRP-supplemented diet	0%, 0.5% and 1.0%	Enhance the palatability of feed	Radwan Nadia et al. (2008)
White Leghorn	103–112 weeks	9 weeks	TRP-supplemented diet	0%, 1.0% and 3.0%	No effect on feed efficiency. Increased FI (3.0%)	Malekizadeh et al. (2012)
White Leghorn	20–24 weeks	4 weeks	TRP-supplemented diet	0, 0.5, 1.0, 1.5, 2 g/kg diet	Decreased FI (1.5 and 2.0 g/kg), and improved FCR (2 g/kg)	Riasi, Kermanshahi, and Mahdavi (2012)
Golden Montazah	29–40 weeks	11 weeks	TRP-supplemented diet	0, 2.0, 3.0, 4.0 and 6.0 g/kg diet	Decreased FI and improved FCR (2.0, 3.0 and 6.0 g/kg). No effect on WG	Samia et al. (2018)
Lohmann Brown	30–36 weeks	6 weeks	TRP-supplemented diet	0.5%	No effect on growth indices	Gumus et al. (2018)
Jabalpur colour layers	32–40 weeks	8 weeks	TRP-supplemented diet	0%, 1.5%, 3.0%, 4.5% and 6%	No effect on growth indices until 4.5%	Chauhan et al. (2018)
White Leghorn	20–24 weeks	4 weeks	TP-supplemented diet	0.1%, 0.2%, and 0.3%	No effect on growth performance	Laganá et al. (2019)

Abbreviation: TRP: turmeric rhizome powder.

received 0 and 1.5 g/kg treatments. Similarly, Samia, Rizk, and El-Sayed (2018) reported that adding 6 g/kg of turmeric powder to the basal diet of layers between 29 and 40 weeks of age significantly decreased feed intake and improved feed conversion, while not affecting body weight gain.

Contrarily, Gumus et al. (2018) found that adding 0.5% turmeric powder to the basal diet had no significant effect on final body weight, feed consumption and FCR in Lohmann Brown layers at 30–36 weeks of age. Chauhan et al. (2018) investigated the impact of including 1.5%, 3%, 4.5% and 6% turmeric powder in layer rations from 32 to 40 weeks of age and observed that the addition of 4.5 g of turmeric powder per kg of feed did not affect feed intake between treatments.

In the study by Malekizadeh, Moeini, and Ghazi (2012), the inclusion of turmeric rhizome powder at 0%, 1% or 3% did not have a significant effect on feed efficiency. However, the group receiving 1% turmeric powder showed a significant decrease in feed consumption compared to the control group (0% and 3% inclusion).

The summarized studies on effect of turmeric on growth indices were presented in Table 4. In summary, different studies have reported varying effects of turmeric supplementation on feed intake, feed conversion, body weight gain and feed efficiency in layers. Although some studies observed a decrease in feed intake and improvement in feed conversion with turmeric supplementation, others found no significant effects. The specific dosage and duration of turmeric supplementation, as well as the age of the layers, may contribute to these discrepancies. Further research is needed to fully understand the implications and optimal usage of turmeric in layer diets.

6 | Effect of Turmeric on Egg Production and Quality

Here is evidence suggesting that incorporating turmeric into the diet of laying hens can stimulate egg production. Radwan Nadia et al. (2008) reported that supplementing layer diets with turmeric powder at a rate of 5 g/kg resulted in increased egg production. Additionally, at a higher supplementation level of 10 g/kg, improvements were observed in internal and external egg qualities such as egg weight, egg mass, yolk weight and yolk index.

The researchers also proposed that turmeric may have a positive effect on the site of calcium deposition in the uterus, which could contribute to increased shell weight and thickness.

In a different study, Sawale et al. (2009) investigated the use of a commercial herbo-mineral toxin binder containing turmeric and found that it alleviated the negative impact of ochratoxin A infection on egg production.

However, not all studies have shown a significant effect of dietary turmeric supplementation on egg production and quality. Moorthy et al. (2009) conducted a study using White Leghorn layers and reported no significant effects of supplementing with 1.0 g/kg of turmeric powder on hen house egg production and percent hen day egg production.

Other studies have yielded different results regarding the effects of turmeric supplementation on egg shell thickness and weight. For instance, Riasi, Kermanshahi, and Mahdavi (2012) and Radwan Nadia et al. (2008) found that supplementing the diets of laying hens with turmeric at 2.0 g/kg and 5.0 g/kg, respectively, did not have a significant impact on egg shell thickness or egg shell weight.

Similarly, Riasi, Kermanshahi, and Fathi (2008) conducted a study where laying hens were fed various levels of turmeric (0.0, 0.5, 1.0, 1.5 and 2.0 g/kg of feed), and they observed no significant effects on specific gravity, egg shell thickness, egg shell weight or the ratio of egg shell weight to egg weight. However, the group receiving 2.0 g/kg of turmeric showed a significant increase in egg mass compared to the groups receiving 1.5, 1.0 and 0 g/kg treatments. There were no notable differences in other egg quality traits, including specific gravity, egg shell thickness (measured in millimetres), egg shell weight (measured in grams) and the ratio of egg shell weight to egg weight, among all the treatments in relation to egg weight. However, the yolk colour significantly improved when 2.0 g/kg of turmeric was added compared to the 0 and 1 g/kg treatments. The study concluded that the inclusion of turmeric in the diet of layers up to 2.0 g/kg did not have any detrimental effects on egg quality.

Additionally, Radwan Nadia et al. (2008) found that egg production, weight and mass showed significant increases in laying hens that were fed a basal diet supplemented with 0.5% turmeric. Furthermore, the group that received 1.0% turmeric in their feed exhibited significantly higher yolk weight and yolk index. The researchers suggested that *Curcuma longa*, the botanical name for turmeric, may enhance the uterine environment, particularly the site where calcium is deposited, leading to an increase in shell weight and thickness.

In another study conducted by Malekizadeh, Moeini, and Ghazi (2012), they found that supplementing the diet of White Leghorn (W-36) laying hens with turmeric meal at rates of 10.0 or 30.0 g/kg did not have any influence on egg production, egg weight or egg mass.

Park et al. (2012) explored the effects of adding different percentages of turmeric (0%, 0.10%, 0.25% or 0.50%) to the feed of laying hens for 7 weeks. They observed that there were no significant differences in egg production or feed intake among the different treatments. However, the group that received 0.5% turmeric showed a significant increase in egg weight. Additionally, the daily egg mass of the turmeric-treated groups was significantly higher compared to the control group. There were no notable differences in shell strength, shell thickness or Haugh unit, except for a significant increase observed in the 0.5% treatment.

In contrast, Gumus et al. (2018) conducted a study with Lohmann Brown layers aged 30–36 weeks and found no significant effect on egg production, albumen index, yolk index, Haugh unit or yolk colour when 0.5% turmeric powder was added to the basal diet.

Similarly, Azouz et al. (2019) discovered that adding 0.25% turmeric powder to the diets of Sinai layers aged 59–74 weeks had no significant effects on egg number per hen, laying rate, egg weight, egg mass per hen, feed intake, FCR, yolk index, yolk percentage, albumen percentage, shell percentage, Haugh unit, net return or economic efficiency. On the contrary, Samia, Rizk, and El-Sayed (2018) conducted a study where they added 6 g/kg of turmeric powder to the basal diet of laying hens between 29 and 40 weeks of age. Their results showed significant improvements in egg number, egg weight, egg mass, shell weight and a decrease in albumin weight. However, no significant effects were observed on yolk weight, yolk index or shell thickness.

Similarly, Chauhan et al. (2018) investigated the effects of including 1.5%, 3%, 4.5% and 6% turmeric powder in layer rations from 32 to 40 weeks of age. They found that adding 4.5 g turmeric powder/kg of feed led to a 53.60% improvement in bird performance in terms of egg production ($p \leq 0.05$). However, there were no significant differences in feed intake, egg weight or egg shell quality among the treatment groups.

These discrepancies in the results regarding egg traits may be attributed to differences in experimental methods used or could potentially be related to the dosage of turmeric used.

In contrast, Malekizadeh, Moeini, and Ghazi (2012) reported an increase in egg production ($p < 0.05$), but no significant change in egg weight, when turmeric rhizome powder was added to the diets of laying hens. The authors suggested that turmeric might enhance the performance of the digestive tract in laying hens, leading to improved egg production.

Van Phuoc et al. (2019) observed that turmeric powder extract improved the production performance of Ac 'Black bone' hens, specifically in terms of egg mass production and feed-to-egg conversion ratio from 28 to 34 weeks of age, whereas no significant change was observed in egg mass.

Park et al. (2012) demonstrated that turmeric powder had a significant effect on egg production but not on egg weight. Meanwhile, Radwan Nadia et al. (2008) suggested that the addition of turmeric could increase egg production and mass due to the potential improvement in the uterine environment, particularly the site of calcium deposition, resulting in enhanced shell weight and thickness.

Recent studies have found that the internal quality of eggs from hens fed turmeric does not differ significantly, as indicated by Lagana et al. (2011), Gumus et al. (2018) and Van Phuoc et al. (2019). However, Saraswati et al. (2013) reported that the addition of turmeric led to a significant increase in albumen height and egg protein. According to Saraswati et al. (2013), this increase in albumen height suggests that the active components in turmeric powder promote the growth of epithelial cells and tubular gland cells in the magnum, which are responsible for synthesizing and secreting albumen.

The constituents of turmeric might also affect the pigmentation of egg yolks, as mentioned by Cho, Zhang, and Kim (2012). In some studies, turmeric and sumac have been used as colorants and flavourings in food products (D. Wang et al. 2016). However, Gumus et al. (2018) found that dietary supplementation of 0.5% turmeric did not have an impact on Haugh unit or yolk colour parameters. Similarly, Radwan Nadia et al. (2008) reported that the addition of turmeric to hen rations did not affect yolk colour and Haugh unit, but it did significantly increase the yolk index.

In one study, the addition of 0.5% turmeric powder to the diet resulted in a 17% increase in yolk colour compared to the control diet after 4 weeks, which aligns with the findings of Riasi, Kermanshahi, and Mahdavi (2012), who observed a significant effect of turmeric rhizome powder on yolk colour after a 4-week study. The authors suggested that the enhancement of yolk colour could be attributed to the yellowish pigment present in turmeric, such as curcuminoids, curcumin and related compounds. However, at the sixth week, yolk colour was slightly lower (about 4%) in laying hens fed 0.5% turmeric compared to the control group, although this difference was not statistically significant ($p > 0.05$). On the other hand, Park et al. (2012) noted a significant increase in yolk colour with the addition of 0.5% dietary turmeric powder.

In summary, while some studies have demonstrated that incorporating turmeric into the diets of laying hens can enhance egg production and improve certain egg quality parameters, such as weight and yolk characteristics, other studies have not observed significant effects. The specific dosage, duration and formulation of turmeric supplementation, as well as the breed and management of the hens, may contribute to the variation in results. Further research is necessary to fully understand the potential benefits and optimal usage of turmeric in improving egg production and quality in laying hens. Some studies on effect of turmeric on egg production and egg quality are presented in Table 5.

7 | Effect of Turmeric on Haematological and Biochemical Parameters

Most experiments conducted on laying hens have focused on the use of turmeric to improve various biochemical parameters in the blood. These parameters include cholesterol fractions, as well as the reduction of serum aspartate transaminase (AST) and alanine aminotransferase (ALT) activities, and triglyceride concentration. In all of these cases, turmeric has been found to be effective in achieving the desired outcomes.

7.1 | Lipid Profile

The changes in plasma lipids in poultry can be complex and require careful interpretation. In laying hens, high levels of plasma lipids often indicate a significant demand for yolk lipids by the developing oocytes. It is important to note that low-density lipoproteins (LDL) and very low-density lipoproteins (VLDL) occur in smaller proportions compared to high-density lipoproteins (HDL) in meat-type chickens. Additionally, the plasma concentration of HDL in laying hens is typically lower by two- to threefold compared to mature hens or broilers (Kim et al. 2022).

Furthermore, it is worth considering that the relationship between lipoprotein metabolism and egg production can be influenced by the age of the bird. For example, hens with higher blood LDL concentrations may experience a decrease in the total number of eggs produced, and highly productive hens tend to have lower LDL levels (Musa et al. 2007). These factors highlight the complexity of lipid metabolism and its association with egg production in poultry.

In the study conducted by Kermanshahi and Riasi (2006), it was observed that supplementation of 0.5–1.5 g/kg turmeric meal resulted in significant reductions of 63.9%, 50.2% and 63.3% in triglyceride, total cholesterol and LDL-cholesterol levels, respectively. On the other hand, the HDL-cholesterol content increased by up to 15%. This study specifically focused on Hy-Line W-36 laying hens and demonstrated the potential of turmeric supplementation in modulating blood lipid profiles by reducing triglyceride, total cholesterol and LDL levels while increasing HDL levels.

Indeed, Riasi, Kermanshahi, and Mahdavi (2012) found that turmeric supplementation had a significant impact on the serum lipid profile of laying hens. In their study, the addition of 0.5 g/kg turmeric meal to the diet resulted in decreased serum levels of triglycerides, total cholesterol and LDL-cholesterol. Additionally, the serum levels of HDL-cholesterol were increased in Hy-Line W-38 laying hens. These findings suggest that turmeric has the potential to positively influence the lipid profile in laying hens by reducing harmful lipids and increasing beneficial ones.

According to Riasi, Kermanshahi, and Mahdavi (2012), the addition of different amounts of turmeric powder to the diet of laying hens had a significant effect on the lipid profile. Specifically, supplementation with 0.5, 1, 1.5 and 2 g/kg of turmeric powder resulted in decreased levels of triglycerides, total cholesterol and LDL-cholesterol compared to the control group. Additionally, the levels of HDL-cholesterol were significantly increased, except for the 2 g/kg treatment.

However, when 1 g/kg of turmeric powder was added to the diet of broiler chickens, Riasi, Kermanshahi, and Mahdavi (2012) did not find a significant effect on various blood parameters including total protein, albumen, globulin, glucose, cholesterol, triglycerides, HDL, LDL and VLDL. This suggests that the impact of turmeric supplementation on blood parameters may differ between laying hens and broiler chickens.

According to Malekizadeh, Moeini, and Ghazi (2012), supplementing the diet of single-comb White Leghorn (W-36) laying hens with turmeric meal at levels ranging from 10.0 to 30.0 g/kg resulted in a reduction of total cholesterol levels in the blood serum. This suggests that higher levels of turmeric meal supplementation can have a beneficial effect on the cholesterol profile of laying hens, potentially contributing to improved health and productivity.

7.2 | Liver Enzyme Activity

Indeed, several studies have reported similar findings regarding the effects of turmeric supplementation on blood lipid profiles and enzyme activities in laying hens. Malekizadeh, Moeini, and Ghazi (2012), Riasi, Kermanshahi, and Mahdavi (2012), Saraswati et al. (2013), and Mirbod et al. (2017) observed reductions in total cholesterol levels when turmeric meal was included in the diet of laying hens.

In terms of enzyme activities, Malekizadeh, Moeini, and Ghazi (2012) found that the supplementation of turmeric meal led to decreased activities of AST and ALT in the blood serum of single-comb White Leghorn (W-36) laying hens. Similar results were reported by Mirbod et al. (2017) and Saraswati et al. (2013).

TABLE 5 | The effect of turmeric on egg production and quality in layers.

Layer breed	Age	Duration of experiment	Source	Doses	Results	References
Al-Salaam	28–40 weeks	12 weeks	TRP-supplemented diet	0%, 0.5% and 1.0%	Increased egg production and egg mass (0.5%). Increased internal and external quality that caused increased fertility and hatchability (1.0%)	Radwan Nadia et al. (2008)
White Leghorn	40 weeks	ND	TP-supplemented diet	1.0 g/kg of diet	No effect on egg production	Moorthy et al. (2009)
White Leghorn	103–112 weeks	9 weeks	TRP-supplemented diet	0%, 1.0% and 3.0%	Increased egg production and egg mass (3.0%)	Malekzadeh et al. (2012)
White Leghorn	20–24 weeks	4 weeks	TRP-supplemented diet	0, 0.5, 1.0, 1.5, 2 g/kg diet	Increased egg yolk colour, while no effect on egg-specific gravity and egg shell thickness	Riasi, Kermanshahi, and Mahdavi (2012)
ND	ND	7 weeks	TRP-supplemented diet	0%, 0.1%, 0.25% and 0.5%	Increased egg weight and egg mass. No effect on egg shell and strength	Park et al. (2012)
Golden Montazah	29–40 weeks	11 weeks	TRP-supplemented diet	0, 2.0, 3.0, 4.0 and 6.0 g/kg diet	Increased egg mass, egg weight and egg number (3.0 and 6.0%)	Samia et al. (2018)
Lohmann Brown	30–36 weeks	6 weeks	TRP-supplemented diet	0.5%	No effect on egg production and quality	Gumus et al. (2018)
Jabalpur colour layers	32–40 weeks	8 weeks	TRP-supplemented diet	0%, 1.5%, 3.0%, 4.5% and 6%	Increased egg production, while no effect on egg weight and egg shell quality	Chauhan et al. (2018)
White Leghorn	20–24 weeks	4 weeks	TP-supplemented diet	0.1%, 0.2%, and 0.3%	No effect on egg quality	Laganá et al. (2019)
Sinai layers	59–74 weeks	15 weeks	TP-supplemented diet	0.25%	Improved egg production, egg number, egg mass and shell weight	Azouz et al. (2019)

Abbreviation: ND: not determined.

However, Gumus et al. (2018) conducted a study where dietary supplementation of 0.5% turmeric did not significantly affect blood serum cholesterol, ALT and AST lvels. This suggests that the effects of turmeric supplementation on blood lipid profiles and enzyme activities may vary depending on the specific experimental conditions and dosage used.

7.3 | Immunoglobulin Titer

Immune system defects can occur with infectious agents (infectious anemia virus, infectious bursal disease virus and Marek virus), nutritional (feed contamination with toxins, mycotoxins, insufficient of vital elements such as vitamins, minerals, amino acids and reduction of feed quality), environmental (temperature, stress and population density) and non-observance of hygiene and biosecurity principles (Gholami-Ahangaran, Fathi-Hafshejani and Hosseini, 2013; Gholami-Ahangaran, Rangsaz and Azizi, 2016). A strong immune response can protect chickens against diseases and infections. Common diseases such as avian influenza and Newcastle disease can have negative effects on egg production and health of poultry (Gholami-Ahangaran, Basiratpour, et al., 2022). An effective immune response can help chickens to perform better performance in stressful conditions by maintaining of egg production. Furthermore, the cost of medicine is reduced and healthy and hygienic products are offered (Gholami-Ahangaran, Zia-Jahromi, and Namjoo, 2014). Therefore, the promotion of immune response in laying hens not only helps to maintain health and improve production, but also increases the quality of poultry products (Wang et al., 2016; Ghasemıan et al., 2022). Sawale et al. (2009) reported that laying hens treated with a herbo-mineral toxin binder containing *Curcuma longa* (turmeric) exhibited an increased haemagglutination titer, indicating an improvement in immune response. Turmeric has been found to enhance the immunity of laying hens in various ways. For instance, Arshami et al. (2013) observed that turmeric supplementation increased total immunoglobulins (Ig) and IgG titers in laying hens after injections of sheep red blood cells (SRBC), indicating an enhanced immune response.

Furthermore, turmeric has been found to boost the immune response to Newcastle disease virus (NDV) and SRBC antigens, as demonstrated by Mirbod et al. (2017). However, it is worth noting that turmeric supplementation in this study also resulted in a decrease in the heterophils to lymphocytes ratio, which may indicate a shift in immune cell populations.

Additionally, Widhowati et al. (2017) found that turmeric, when used as a feed supplement, increased the number of heterophil and basophil cells and exhibited an immunostimulatory effect in layer chickens vaccinated against avian influenza.

These studies collectively suggest that turmeric has immunomodulatory properties and can positively influence the immune response in laying hens, leading to improved immunity and potentially better overall health.

In conclusion, the findings of this review highlight the potential of turmeric as a natural and cost-effective intervention for improving layer health and egg production. Incorporating turmeric into layer diets can offer sustainable benefits by reducing the reliance on synthetic additives or medications. Moreover, turmeric supplementation aligns with the growing consumer demand for natural and organic poultry products. However, further research is needed to optimize dosage regimens, evaluate long-term effects and elucidate the underlying mechanisms of turmeric's actions in promoting layer health and egg production. Additionally, studies should explore the specific modes of administration and the bioavailability of curcumin to maximize its efficacy.

Author Contributions

Saade Abdalkareem Jasim: conceptualization, funding acquisition, supervision, writing–original draft. **Aiman Mohammed Baqir Al-Dhalimy**: data curation, methodology, software, visualization. **Maryam Zokaei**: formal analysis, investigation, methodology, software, validation. **Shadi Salimi**: formal analysis, investigation, methodology, software, validation. **Mohammed Jawad Alnajar**: investigation, validation, visualization. **Abhinav Kumar**: data curation, writing–original draft. **Enas R. Alwaily**: project administration, resources, validation. **Ahmed Hussein Zwamel**: formal analysis, resources, software, validation, visualization. **Soura Alaa Hussein**: investigation, validation, writing–review and editing. **Majid Gholami-Ahangaran**: Project administration, conceptualization, investigation, methodology, supervision, writing–original draft, writing–review and editing.

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The authors have nothing to report.

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The authors declare no conflicts of interest.

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All data are available and reserved in near of corresponding author. The requests are answered.

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