

## Biological Functions of Tea Polyphenols and Their Application in Poultry Production (Post-print)

**Authors:** Wang Xiaohong, Wu Shugeng, Wang Xiaocui, Wang Jing, Zhang Haijun

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### Abstract

Tea polyphenols are the general term for polyphenolic compounds in tea and function as natural antioxidants widely used in livestock and poultry farming. This review summarizes the composition and active components, biological functions, and mechanism of action of tea polyphenols, as well as their application in poultry production, aiming to provide a theoretical basis for the scientific application of tea polyphenols in poultry production.

### Full Text

## Biological Functions and Mechanisms of Tea Polyphenols and Its Application in Poultry Production

\*\*WANG Xiaohong, WU Shugeng\*, WANG Xiaocui, WANG Jing, ZHANG Haijun\*\*

(National Engineering Research Center of Biological Feed, Key Laboratory of Feed Biotechnology of Ministry of Agriculture, Feed Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China)

**Abstract:** Tea polyphenols are the general term for polyphenolic compounds in tea and serve as natural antioxidants that are widely used in livestock feeding. This paper reviews the composition and active ingredients of tea polyphenols, their biological functions, mechanisms of action, and applications in poultry production, aiming to provide a scientific basis for the rational application of tea polyphenols in poultry production.

**Key words:** tea polyphenols; biological function; mechanisms; antioxidation; poultry production

Corresponding author: WU Shugeng, associate professor, E-mail: wushugeng@caas.cn

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## 1 Composition and Active Ingredients of Tea Polyphenols

Tea polyphenols are flavonoid compounds extracted from tea leaves and their by-products, with -phenylbenzopyran as their structural backbone. They possess various physiological functions including antioxidant, antibacterial, antiviral, gut microbiota modulation, immune enhancement, and lipid metabolism regulation. Dietary supplementation with appropriate amounts of tea polyphenols can enhance immune function, improve production performance, and enhance product quality. Also known as tea catechins, tea polyphenols constitute 30%-42% of the dry weight of green tea products. They comprise a complex mixture of catechins (flavanols), flavones and flavonols, anthocyanins, phenolic acids, depsides, and small amounts of caffeine. Catechins account for approximately 70% of total tea polyphenols and include five main compounds: D-catechin (DC), epicatechin (EC), epigallocatechin (EGC), epigallocatechin gallate (EGCG), and epicatechin gallate (ECG). Among these, the esterified EGCG (comprising 50%-80% of total catechins) exhibits the highest antioxidant activity. In antioxidant processes, ECG and EGCG provide primary synergistic effects, while flavonols interact with catechins to confer stronger antioxidant capacity than individual components.

Although tea polyphenols demonstrate superior antioxidant effects compared to common antioxidants such as butylated hydroxyanisole (BHA) and 2,6-di-butyl-4-methyl phenol (BHT), practical applications face several limitations. These include poor lipid solubility, high product variability, functional instability, susceptibility to inactivation, and inconsistent decaffeination levels, which severely affect their practical efficacy. In recent years, improved extraction and separation technologies have increased product yield while reducing caffeine content and costs. Single-marker multi-component quantitative analysis has been applied to evaluate the quality of tea extracts. Modified tea polyphenols (through acetylation, esterification, etc.) exhibit good lipid solubility and can be used as lipid-soluble antioxidants. Microencapsulated tea polyphenols are less prone to oxidative inactivation, though their application is limited by higher costs. Current research has utilized nanotechnology to encapsulate tea polyphenols in gelatin nanoparticles, significantly enhancing their biological activity.

## 2 Biological Functions and Mechanisms

### 2.1 Antioxidant Effects

As natural antioxidants, tea polyphenols can improve poultry production performance. Oxidative stress frequently occurs in poultry production, leading to reduced feed intake, gastrointestinal dysfunction, and consequently impaired production performance. When animals experience stress, excessive free rad-

icals are generated. When these exceed the body's reducing capacity, free radical metabolism becomes imbalanced, resulting in oxidative stress that can cause severe oxidative damage. Tea polyphenols can alleviate poultry stress and improve animal health through their antioxidant properties.

**2.1.1 Direct Free Radical Scavenging** The B and C rings of tea catechins contain ortho- or para-phenolic hydroxyl groups. The electrons in the benzene ring conjugate with unpaired single electrons in oxygen atoms, causing the unpaired electrons to delocalize toward the benzene ring and weakening the hydroxyl hydrogen bonds. This confers tea catechins with relatively active hydroxyl hydrogens. During oxidation, tea catechins generate ortho-quinones and biphenol quinones while providing hydrogen ions (H<sup>+</sup>) that combine with oxygen and lipid free radicals to form inert compounds, thereby terminating free radical chain reactions. Consequently, tea catechins can scavenge not only free radicals generated in chain reactions but also intermediate products (lipid peroxy and alkoxy radicals), eliminating lipid peroxidation, DNA oxidative damage, and biomembrane injury caused by excessive free radicals. During free radical scavenging, tea polyphenols form various oxidation products with strong antioxidant activity, including biflavonols, theaflavins, and thearubigins, which complicates the antioxidant pathways of tea polyphenols.

**2.1.2 Indirect Free Radical Scavenging** Tea polyphenols regulate the activity of oxidation-related and antioxidant enzymes, thereby indirectly acting on free radicals to protect the body from oxidative damage. Studies have shown that the polyphenolic structure can chelate more than ten types of metal ions, including iron, calcium, and copper, inhibiting metal ion-mediated or catalyzed lipoprotein oxidation and oxidase activity while protecting antioxidant enzyme activity. EGCG protects erythrocyte membrane-bound ATPase to alleviate oxidative stress. Additionally, tea polyphenols can significantly upregulate mRNA and protein expression levels of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) in cells, increasing SOD, CAT, and GSH-Px activity in culture media to scavenge oxygen free radicals and reduce mitochondrial oxidative damage.

**2.1.3 Other Pathways** Tea polyphenols can also regenerate and protect endogenous vitamin C and vitamin E, synergistically enhancing antioxidant effects with these vitamins. This is consistent with findings that tea polyphenols increase vitamin E content in low-density lipoprotein (LDL) and inhibit LDL lipid peroxidation. EGCG modulates the body's antioxidant capacity by regulating the expression of the transcription factor nuclear factor erythroid 2-related factor 2 (Nrf2) in redox reactions. It alleviates heat stress in quails by inhibiting hepatic nuclear factor kappa B (NF- $\kappa$ B) and promoting Nrf2 expression. EGCG also attenuates NADPH oxidase activity induced by traumatic brain injury by inhibiting p47phox translocation. In a mouse model of oxidative stress induced by hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), EGCG reduced H9c2 cell oxidative damage by

regulating the Akt/GSK-3 signaling pathway and affecting caveolin activity. These results demonstrate that tea polyphenols utilize their structural characteristics to directly scavenge and inhibit free radicals, activate intracellular antioxidant defense systems, and modulate hormone levels, enzyme genes, and transcription factor expression related to antioxidant activity. Through multiple mechanisms, they alleviate oxidative stress and safeguard animal health.

## 2.2 Antimicrobial Effects

Tea polyphenols exhibit broad-spectrum antimicrobial activity and have been used as food preservatives in livestock product processing and storage for the preservation of aquatic products, oils, fats, and meats. Dietary supplementation with tea polyphenols can inhibit bacterial growth, extend shelf life, and when fed to poultry, exert antibacterial, antiviral, and gut health-improving effects while enhancing disease resistance.

The multiple phenolic hydroxyl groups in tea polyphenol molecules can form hydrogen bonds with amino or carboxyl groups in protein molecules, while their hydrophobic benzene rings interact hydrophobically with proteins. This multi-point binding provides the fundamental conditions for antimicrobial activity. Metal ions serve as cofactors for certain enzymes and are essential nutrients for microorganisms. Tea polyphenols inhibit microbial growth and proliferation by chelating metal ions and affecting enzyme activity and microbial metabolism. Research shows that polyphenols can inhibit bacteria by altering bacterial cell membrane permeability, inhibiting extracellular enzyme activity, directly affecting microbial metabolism, and influencing microbial absorption of essential nutrients. This is consistent with findings that catechins can destroy phospholipid bilayer structures and cause cell death, suggesting that tea polyphenols may indirectly affect microbial metabolism by disrupting cell membrane structure and altering permeability. Other studies have demonstrated that tea polyphenols directly affect *E. coli* DNA, causing darkening and tailing in gel electrophoresis. EGCG inhibits bacterial proliferation by reducing bacterial population, affecting the production of quorum sensing molecules, and consequently inhibiting the release of virulence factors and biofilm formation. Under neutral or weakly alkaline conditions, tea polyphenols can also inhibit bacterial proliferation by generating hydrogen peroxide. These findings indicate that the antimicrobial activity of tea polyphenols results from multiple mechanisms, including metal ion chelation, cell membrane permeability alteration, and effects on signaling molecule production and related gene expression to inhibit harmful microbial metabolism, growth, and proliferation. Furthermore, tea polyphenols alleviate diseases caused by bacteria. Recent research shows that green tea extract can inhibit *Helicobacter pylori*-induced gastric disease without affecting beneficial gut microorganisms. EGCG can alleviate endotoxin-induced nerve damage and shows positive effects on inflammation-induced neurodegenerative diseases.

### 2.3 Regulation of Lipid Metabolism

Polyphenolic compounds can regulate lipid digestion and absorption in the intestine. Studies have shown that green tea catechins can reduce blood cholesterol (TC) and triglyceride (TG) levels in rats fed high-fat diets. Combined use of EGCG with other esterified catechins significantly enhances TC flocculation capacity, reducing TC dissolution and absorption in the small intestine. EGCG interaction with taurocholic acid can decrease the solubility of lecithin and TC in micellar solutions. High levels of EGCG and ECG dose-dependently inhibit postprandial elevation of blood TG levels. These results suggest that tea polyphenols inhibit intestinal lipid digestion and absorption, possibly through different mechanisms: EGCG and other catechins may inhibit lipid dissolution and potentially regulate intestinal digestive enzyme activity. Further research is needed to elucidate the mechanisms of tea polyphenols' effects on intestinal lipid digestion and absorption.

Tea polyphenols also regulate the expression of lipid metabolism-related genes. Research indicates that green tea polyphenols can downregulate hepatic lipogenic gene expression while significantly upregulating genes related to lipid transport and metabolism, such as carnitine palmitoyltransferase (CPT-I), acyl-CoA oxidase 1 (ACOX1), and peroxisome proliferator-activated receptor (PPAR), as well as adipose triglyceride lipase (ATGL) in abdominal fat and lipoprotein lipase (LPL) in skeletal muscle. By inhibiting fatty acid synthesis and stimulating lipolysis, they reduce fat deposition and serum lipid levels in broiler chickens. Long-term feeding of tea polyphenols and *Lactobacillus brevis* M8 to broilers reduces intestinal cytokine and NF- $\kappa$ B mRNA expression levels while promoting pancreatic lipase and proventriculus pepsin activity, thereby improving lipid metabolism. These findings demonstrate that mediating the expression levels of lipid metabolism enzyme-related genes and regulating lipogenic enzyme activity constitute important mechanisms by which tea polyphenols modulate lipid metabolism.

The above studies indicate that tea polyphenols improve lipid metabolism by inhibiting exogenous lipid digestion and absorption in the intestine, regulating lipid metabolism-related gene expression, reducing serum TC and TG contents, and modulating PPAR, PPAR $\alpha$ , and PPAR $\gamma$  expression at both mRNA and protein levels in adipose tissue, liver, and heart. Additionally, tea polyphenols can activate adenosine monophosphate-activated protein kinase in liver, bone, and adipose tissue, thereby reducing carbohydrate and fatty acid synthesis while promoting their catabolism and alleviating obesity and related metabolic syndromes.

The mechanisms of tea polyphenols' antioxidant, antimicrobial, and lipid metabolism-regulating effects are not limited to direct actions based on their structural characteristics. They can also modulate related enzyme genes and transcription factor expression, thereby establishing a dynamic balance among lipid metabolism, endocrine function, and antioxidant capacity through more

efficient and extensive means to maintain animal health. Studies show that tea polyphenols can reduce corticosterone-induced oxidative stress and improve hyperlipidemia and growth inhibition in broiler chickens. They regulate lipid metabolism in laying hens by modulating hepatic, plasma, and yolk lipids, increasing plasma estradiol and insulin levels, and influencing lipoprotein and apolipoprotein synthesis through the neuroendocrine system. Tea polyphenols also ameliorate the adverse effects of high-fructose diets on cardiac insulin signaling, lipid metabolism, and inflammatory responses in rats, with anti-inflammatory effects regulating mRNA genes involved in insulin secretion, lipid metabolism, and inflammatory responses in the heart.

### 3 Application of Tea Polyphenols in Poultry Production

In recent years, frequent food safety issues have affected consumer confidence in animal products. As natural antioxidants, plant polyphenols offer advantages such as high efficiency and safety, and can be used to improve animal health, reduce antibiotic usage, and alleviate contamination of animal products.

#### 3.1.1 Broiler Production

During broiler production, both chronic and acute stress (such as heat, immune, catching, and transport stress) are unavoidable. Stress stimulates the hypothalamic-pituitary-adrenal axis to release adrenocorticotropic hormone and glucocorticoids (GC). Excessive GC accumulation promotes muscle fiber protein catabolism while reducing synthesis, leading to slow muscle growth and atrophy. When homeostasis and the oxidant/antioxidant balance are disrupted, oxidative stress occurs, reducing feed intake and daily weight gain while increasing mortality and deteriorating meat quality. Numerous animal experiments have demonstrated that tea polyphenols significantly increase total antioxidant capacity (T-AOC) and GSH-Px activity in blood while reducing malondialdehyde (MDA) content in breast and thigh muscles of broilers fed dried distillers grains with solubles (DDGS) diets, thereby improving antioxidant status in both the body and meat quality. Green tea extract exhibits anti-avian influenza FAdV-4 activity superior to that of individual catechins such as ECG, EGC, and EGCG. Green tea extract can also reduce thiobarbituric acid reactive substances (TBARS) in rooster semen, protecting sperm membranes from peroxidative damage and thus improving reproductive performance. Supplementation with 1% oolong tea powder significantly reduces subcutaneous and intermuscular fat thickness in meat ducks, improving fat deposition. Recent research has replaced vitamin E with grape polyphenols in broiler diets, which not only maintains normal growth but also improves antioxidant and immune status while reducing feed costs. Feeding grape pomace protects  $\alpha$ -tocopherol in broilers, reduces muscle lipid oxidation susceptibility, and increases polyunsaturated fatty acid content. Under heat stress conditions, feeding polyphenolic compounds extracted from tamarind increases lymphocyte numbers and relative bursa weight while reducing bursal lesions in broilers. These results demonstrate that plant polyphenol

extracts applied in broiler production can significantly reduce lipid peroxidation levels in the body and meat, enhance immunity, and improve meat quality. Furthermore, combined use of tea products with other effective substances has become a research hotspot in livestock production, yielding excellent results in applied innovation. Studies show that adding 2% fish oil and 1.5% green tea improves gastrointestinal microbial health in broilers, and their combined use can reduce feed costs and improve production performance. The combination of biotite and green tea in broiler diets can serve as an antibiotic alternative to maintain healthy broiler growth.

Tea polyphenol products are being widely applied as safe and effective feed additives to improve various production indicators, providing a theoretical basis for producing healthy meat by improving gut health and enhancing antioxidant and immune status in poultry.

### 3.1.2 Layer Production

Haugh unit is an indicator of albumen quality and egg freshness. As storage time extends, thick albumen becomes thinner and Haugh unit decreases. Studies have shown that adding tea polyphenols to layer diets can delay Haugh unit reduction during egg storage, significantly decrease yolk cholesterol and MDA content, and extend egg shelf life. Dietary supplementation with 6 g/kg green tea or 1 g/kg tea catechins significantly reduces TC, TG, and LDL levels in blood and muscle while increasing blood high-density lipoprotein (HDL) and yolk unsaturated fatty acid content. Yolk vitamin E content increases with green tea supplementation levels. Resveratrol, a polyphenolic compound extracted from peanuts, grapes, and mulberries, reduces TBARS in serum and yolk while increasing serum vitamin E levels in quails. Quercetin, rich in flavonoids, improves production performance in laying hens by modulating the intestinal environment. These results indicate that polyphenolic compounds can reduce cholesterol levels in serum and yolk of laying birds, improve lipid metabolism and yolk fatty acid composition, enhance antioxidant capacity, and delay oxidation during egg storage. However, some studies have shown that although tea catechins improve quail fertility and hatchability and extend egg shelf life, they reduce egg weight and eggshell quality. This result is consistent with previous research and may be attributed to excessively high tannic acid content in the added tea products.

Numerous studies have investigated the effects of tea polyphenols alone or in combination with ascorbic acid, vitamin E, selenium yeast, and lactic acid bacteria on improving antioxidant capacity, immunity, lipid metabolism, and poultry product quality. However, conclusions regarding the dose-response relationship of green tea and polyphenols in poultry vary, systematic studies on optimal doses for different livestock species are lacking, and the safety of high-dose usage cannot be ignored.

### 3.2 Application Dosage of Tea Polyphenols in Poultry Production

In production practice, the dosage of tea polyphenols, green tea powder, or EGCG in diets varies, resulting in different effects (Table 1).

**Table 1** The optimal doses and corresponding effects of tea products

Items	Additive	Optimal dose/%	Application effect
Layer	Tea polyphenols (TP)	0.01-0.04	Extend egg shelf life, reduce yolk cholesterol; improve laying rate, reduce feed-to-egg ratio
	Green tea powder	0.01-0.02	Improve laying rate and egg weight, reduce feed-to-egg ratio
	Green tea extracts	0.01-0.02	Improve production performance (reduce feed-to-weight ratio, improve feed efficiency)
Broiler	Tea polyphenols (TP)	0.03	Improve antioxidant capacity in body and meat of broilers fed high-DDGS diets
	Green tea powder	0.02, 0.04	Anticoccidial effect, antibiotic alternative in broiler production
Quail	Catechin	0.02, 0.04	Improve reproductive performance under heat stress, alleviate oxidative stress

Tea polyphenols can regulate the dynamic balance among lipid metabolism, endocrine function, and antioxidant capacity in animals, thereby enhancing immune function and improving production performance and product quality. Although numerous reports exist on the antioxidant, antimicrobial, and lipid metabolism-regulating effects of tea polyphenols, their specific mechanisms of action remain unclear. Few reports address the bioavailability, effective and tolerable concentrations, and existing forms of tea polyphenols in vivo. Issues such as poor stability and susceptibility to oxidation require urgent resolution, and the application dosage and form of tea polyphenols as feed additives in practical production require further exploration and research.

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*Note: Figure translations are in progress. See original paper for figures.*

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