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REVIEW ARTICLE

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Nutritional applications and beneficial health applications of green tea and L-theanine in some animal species: A review

Mahmoud Alagawany[1] | Mohamed E. Abd El-Hack[1] | Muhammad Saeed[2] | Muhammad Naveed[3,4] | Muhammad A. Arain[5] | Muhammad Arif[6] | Ruchi Tiwari[7] | Rekha Khandia[8] | Sandip K. Khurana[9] | Kumaragurubaran Karthik[10] | Mohd. I. Yatoo[11] | Ashok Munjal[8] | Prakash Bhatt[12] | Khan Sharun[13] | Hafiz M. N. Iqbal[14] | Chao Sun[5] | Kuldeep Dhama[15]

[1]Poultry Department, Faculty of Agriculture, Zagazig University, Zagazig, Egypt

[2]Department of Animal Nutrition, Cholistan University of Veterinary and Animal Sciences Bahawalpur, Pakistan

[3]Faculty of Pharmacy and Alternative Medicine, Islamia University of Bahawalpur, Bahawalpur, Pakistan

[4]Department of Clinical Pharmacy, School of Basic Medicine, and Clinical Pharmacy, China Pharmaceutical University, Nanjing, Jiangsu Province, China

[5]College of Animal Science and Technology, NW A&F University, Yangling, Shaanxi, China

[6]Department of Animal Sciences, University College of Agriculture, University of Sargodha, Pakistan

[7]Department of Veterinary Microbiology and Immunology, College of Veterinary Sciences, UP Pandit Deen Dayal Upadhayay Pashu Chikitsa Vigyan Vishwavidyalay Evum Go-Anusandhan Sansthan (DUVASU), Mathura, Uttar Pradesh, India

[8]Department of Genetics, Barkatullah University, Bhopal, India

[9]ICAR-Central Institute for Research on Buffaloes, Hisar, Haryana, India

[10]Central University Laboratory, Tamil Nadu Veterinary and Animal Sciences University, Chennai, Tamil Nadu, India

[11]Sher-E-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu and Kashmir, India

[12]Teaching Veterinary Clinical Complex, College of Veterinary and Animal Sciences, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Udham Singh Nagar), Uttarakhand, India

[13]Division of Surgery, ICAR-Indian Veterinary Research Institute, Uttar Pradesh, Izatnagar, Bareilly, India

[14]School of Engineering and Science, Tecnologico de Monterrey, Campus Monterrey, Monterrey, NL, Mexico

[15]Division of Pathology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

Correspondence
Mahmoud Alagawany, Poultry Department, Faculty of Agriculture, Zagazig University, Zagazig 44511, Egypt.
Email: mmalagwany@zu.edu.eg

Kuldeep Dhama, Division of Pathology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly 243 122, Uttar Pradesh, India.
Email: kdhama@rediffmail.com

Abstract

Green tea (*Camellia sinensis*) is a popular herbal plant with abundant health benefits, and thus, it has been used as a potent antioxidant for a long time. Based on the available literature, the diversity and the availability of multifunctional compounds in green tea offer its noteworthy potential against many diseases such as liver and heart diseases, inflammatory conditions and different metabolic syndromes. Owing to its bioactive constituents including caffeine, amino acids, L-theanine, polyphenols/flavonoids and carbohydrates among other potent molecules, green tea has many pharmacological and physiological effects. The effects of green tea include anti-oxidative, anti-inflammatory, anti-arthritic, anti-stress, hypolipidaemic, hypocholesterolaemic, skin/collagen protective, hepatoprotective, anti-diabetic, anti-microbial, anti-infective, anti-parasitic, anti-cancerous, inhibition of tumorigenesis and angiogenesis, anti-mutagenic, and memory and bone health-improving activities. Apart from its utilization in humans, green tea has also played a significant role in livestock production such as in dairy, piggery, goatry and poultry industries. Supplementation of animal feeds with green tea and its products is in line with the modern concepts of organic livestock production. Hence, incorporating green tea or green tea by-products into the diet of poultry and other livestock can enhance the value of the products obtained from these animals. Herein, an effort is made to extend the knowledge on the importance and useful applications of green tea and its important constituents in animal production including poultry. This review will be a guideline for researchers and entrepreneurs who want to explore the utilization of feeds supplemented with green tea and green tea by-products for the enhancement of livestock production.

KEYWORDS

animals, Green tea, growth performance, health, L-theanine, poultry

1 | INTRODUCTION

The addition of various nutritional supplements and additives to foods/diets including growth promoters, antioxidants, nutraceuticals, herbs, green tea, coffee, probiotics and others for enhanced production performances, improved immunity, and health benefits in humans, animals, poultry, and other species is showing an increasing trend (Dhama et al., 2015; Dhama, Tiwari, Chakrabort, et al., 2014; Dhama, Tiwari, Khan, et al., 2014; Laudadio et al., 2015; Mahima et al., 2013; Suez, Zmora, Segal, & Elinav, 2019; Xing, Zhang, Qi, Tsao, & Mine, 2019). Particularly, plants, herbs and shrubs that possess high medicinal values have attracted the attention of worldwide researchers owing to their multiple beneficial health applications (Abd El-Hack & Alagawany, 2015; Alagawany et al., 2019; Mahima et al., 2012; Tiwari et al., 2018; Velmurugan, Kalpana, Cho, & Lee, 2018; Yatoo et al., 2017). Nowadays, green tea is becoming popular (Cooper, 2012; Saeed, Naveed, et al., 2017) as it is the second most-consumed beverage throughout the world (Conde, Alves, Oliveira, & Silva, 2015). The leaves of green tea contain anti-oxidative catechins (Varilek et al., 2001) which have many health benefits such as anti-inflammatory, anti-arthritic, anti-carcinogenic, anti-cancerous, anti-mutagenic, anti-oxidative, anti-microbial, anti-bacterial, anti-viral, anti-fungal, anti-coccidial, anti-parasitic, anti-infective, hypocholesterolaemic, resistance to capillary blood congestion and hypolipidaemic effects (Butt, Ahmad, Sultan, Qayyum, & Naz, 2015; Fujiki, Watanabe, Sueoka, Rawangkan, & Suganuma, 2018; Mohamed, El-Hindawy, Alagawany, Salah, & El-Sayed, 2019; Saeed, Naveed, et al., 2017; Varilek et al., 2001). There are various types of tea but the main types such as green tea (*Camellia sinensis* L.), white (less processed) tea, oolong tea and black tea (Lee, Kim, Kim, & Kim, 2014) have been found to be beneficial for health. Among these, green tea (*Camellia sinensis*) is a popular herbal plant used as an antioxidant with abundant health benefits and also considered as one of the most well-known beverages in the world mostly due to its prospective health benefits (Cooper, 2012; Delwing-Dal Magro et al., 2016; Saeed, Naveed, et al., 2017). The bioactive constituents of green tea include caffeine, L-theanine, polyphenols/ flavonoids, catechins (epigallocatechin-3-gallate [EGCG], epicatechin-3-gallate [ECG], EC-glucuronide, EC-sulphate, and EGC-glucuronide), and other potent molecules (Saeed, Naveed, et al., 2017; Xing et al., 2019). L-theanine (γ-Glutamylethylamide) is a non-protein amino acid discovered in the leaves of *Camellia sinensis* in 1949 (Deng, Ogita, & Ashihara, 2010). L-theanine has been studied as a food additive and functional food in relation to human nutrition, and it has health-promoting, pharmacological and biological properties such as anti-cerebral ischaemia-reperfusion injury, stress-reducing, antitumour, anti-ageing and anti-anxiety activities (Culetu, Fernandez-Gomez, Ullate, Maria, & Wilfried, 2016; Saeed, Naveed, et al., 2017). Green tea polyphenols (GTPs) increase the quality of male and female gametes mainly due to catechins which reduce the level of reactive oxygen species (ROS) both in humans and animals thereby improving fertility (Rahman et al., 2018). This article describes the useful applications and practical utility of green tea and L-theanine as feed supplement to improve production performances and provide potential health applications in livestock animals including poultry, fish and others. Multiple beneficial applications of green tea have been demonstrated in dairy, piggery, goatry and poultry industries; in pet animals (dogs) and fishes; and in mice, rat, and fruit fly models. A special focus has been given to green tea and L-theanine in poultry production including the role of L-theanine as a natural anti-stressor in poultry diets.

2 | BENEFITS OF GREEN TEA AND L-THEANINE

Green tea leaves have many beneficial health activities including anti-inflammatory, anti-carcinogenic, anti-mutagenic, anti-oxidative, anti-microbial and hypolipidaemic effects (Rothenberg & Zhang, 2019; Varilek et al., 2001). There are studies in the literature with reports that catechins of green tea are capable of binding with minerals thereby influencing their metabolism and concentration (Nelson & Poulter, 2004; Saeed, Abd El-Hack, et al., 2017; Zijp, Korver, &

Tijburg, 2000). Excess intake of catechins reduces the levels of zinc and iron, increases the level of manganese, but does not affect the concentration of copper; however, the final blood plasma concentrations of the minerals were not significantly altered in a study conducted among the healthy people of United Kingdom (Nelson & Poulter, 2004). After oral administration in rats, L-theanine was smoothly absorbed into the bloodstream and transferred to the major organs such as the brain, where after 15 and 30 min of oral administration, the percentage of theanine incorporated into the brain were 0.23% and 0.39% respectively (Terashima, Takido, & Yokogoshi, 1999). Peng, Liu, Lin, Lin, and Huang (2014) found that L-theanine can increase the levels of 5-hydroxytryptamine (5-HT) and decrease the levels of adrenocorticotropic hormone, corticosterone (CORT) and noradrenaline in the hippocampus and prefrontal cortex of rats. Wen et al. (2012) demonstrated that the addition of 400 mg L-theanine/kg to daily diet increases the level of secretory IgA in the jejunum and the levels of IL-2 and IFN-γ in the serum of chickens. Dietary supplementation with L-theanine in pigs led to improved body weight gain and enhanced production of anti-inflammatory cytokines (Hwang et al., 2008). In mice, L-theanine as a natural antioxidant showed neuroprotective effects against chronic stress-induced cognitive impairments (Tian et al., 2013). Tamano et al. (2013) reported that young rats treated with water containing 0.3% L-theanine for a period of 3 weeks post-weaning followed by exposure to water-immersion stress for 30 min had lower serum CORT level than those in the control group. Similarly, Takeda et al. (2012) reported that there was a significant reduction in the serum CORT level of young rats administered water supplemented with 0.3% L-theanine after birth in comparison with the control animals. Furthermore, Cui et al. (2011) reported that L-theanine showed significant antidepressant-like effect in mice. Several previous studies in the literature focused on in vitro experiments in different subjects such as humans, cattle, pigs and rats.

L-theanine reduces the toxic side effects associated with anticancer drugs, as well as lipid peroxidation and glutathione peroxidase enzyme activity induced by doxorubicin (DOX) drug, thereby ameliorating oxidative stress (Liang, Chang, Xiang, & Zheng, 2015; Zhang, Geng, Chen, Zhao, & Wang, 2019). The derivatives of L-theanine inhibit tumour growth by targeting vascular endothelial growth factor receptor-Akt/epidermal growth factor receptor/nuclear factor-kappa B (EGFR/VEGFR-Akt/NF-kappa B) signalling pathways which control cell proliferation and survival. Ethyl 6-nitrocoumarin-3-carboxylyl L-theanine and ethyl 6-fluorocoumarin-3-carboxylyl L-theanine prevent the growth of lung cancer cell in vivo, in vitro and ex vivo by targeting the aforementioned pathways (Zhang et al., 2014). Green tea supplementation for guinea pigs might be helpful in reducing the deleterious effects of electromagnetic radiation-induced changes in the levels of manganese, iron, copper and the copper/zinc ratio in the liver and the testis (Kilicalp, Dede, Deger, & Aslan, 2009). On the other hand, use of L-theanine in broiler diets

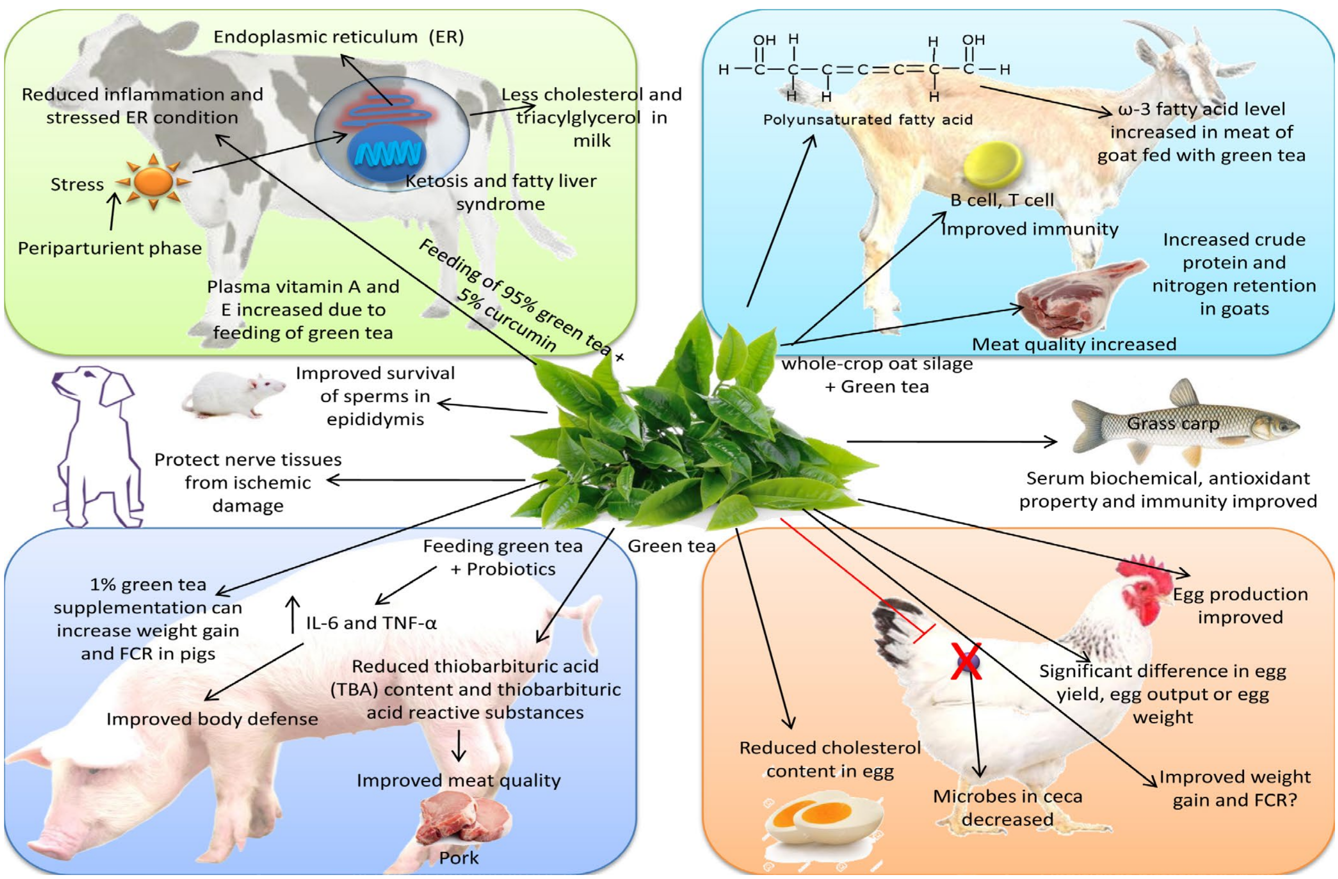

FIGURE 1 Salient beneficial effects of green tea in animals

exhibited a positive effect on intestinal bacteria by decreasing harmful microbes such as Clostridium and supporting beneficial bacteria such as Lactobacillus (Saeed, Yatao, Tiantian, Qian, & Chao, 2019).

3 | BENEFICIAL APPLICATIONS IN ANIMALS

Salient beneficial effects of green tea in animals are presented in Figure 1.

3.1 | Dairy

During the periparturient phase, cows experience the induction of stressed condition in the endoplasmic reticulum (ER) leading to ketosis and fatty liver syndrome. In the study of Winkler et al. (2015), the authors found that the supplementation of cow feed with a combination of 95% green tea and 5% curcumin extract to dairy cows could reduce inflammation and alleviate stressed ER condition in lactating cows. At post-partum, the milk had less level of cholesterol and triacylglycerol up to the third week post-partum compared to control cows. In addition, cows fed with supplemented feed showed a reduction in haptoglobin mRNA level (Winkler et al., 2015). Holstein steers fed with diet containing 20% green tea waste silage showed increased plasma concentrations of vitamin A and E, which protects the cattle from oxidative damage (Nishida et al., 2006). Green tea extract (GTE) was added (0.028% of dry matter) to the feed of lactating Holstein/Holstein-Gir dairy cows; however, the diet did not alter the milk yield or most of the milk characteristics but reduced the emission of methane gas. Therefore, GTE may be used as a food additive (Kolling et al., 2018) for a sustainable environment. Dairy cows were exposed to oxidative stress and fatty liver disease during the periparturient phase, and thereafter, the absorption of GTE (containing catechins with proven anti-inflammatory, anti-oxidative and hepatoprotective effects) in cattle plasma after intraruminal and intraduodenal administration was documented. The experiment encompassed the rumen-fistulated non-lactating heifers and duodenal fistulated lactating dairy cows, where GTE was applied intraruminally and intraduodenally respectively. The concentrations of major catechins were determined in the plasma by HPLC and the study revealed that intraruminal or orally administered catechins were metabolized by rumen micro-organism, and hence did not appear in blood plasma. Contrary to this, intraduodenal administration resulted in increased concentration of catechins in the plasma (Wein et al., 2016). Green tea waste which is obtained after tea production can be utilized for silage production. When green tea waste was added to by-product-mixed silage, an increase in acid production was observed which resulted in the lowering of pH along with reduced dry matter loss (Kondo, Kita, & Yokota, 2006). The addition of green tea waste in mixed silages also lowered the tannin content of silage mix and in vitro ruminal gas production.

3.2 | Piggery

Poor grade green tea as well as residues of green tea beverage production often termed as green tea by-products (GTBs) are known to have positive effects on pig health. In pork, GTBs has been reported to reduce the indices of lipid oxidation—thiobarbituric acid (TBA) content and thiobarbituric acid reactive substances (TBARS) value thereby improving meat quality (Sarker, Yim, et al., 2010). Feeds supplemented with 1% green tea helped to improve feed conversion efficiency and body weight gain in pigs. The addition of GTB and green tea with probiotics (GT + P) which include *Bifidobacterium long*, *B. infants*, *B. breve* and *Lactobacillus helveticus*, *L. plantarum*, *L. cases* and *L. rhamnosu* reduced TBARS value. Lymphocyte proliferation test following Concanavalin A (Con A) and lipopolysaccharide (LPS) stimulation showed better lymphoproliferation in green tea- and probiotic-fed pig (Ko & Yang, 2008). Chevon patties treated with 2% GTE were tested for physicochemical and organoleptic qualities, and the results revealed that the pH and the TBA values were significantly lowered with a reduced viral load (Nath, Kumar, Praveen, & Ganguly, 2016). The biochemical parameters and sensory properties of pork patties treated with irradiated GTE were analysed. A decreased lipid peroxidation as well as improved colour and aroma were observed in the treated pork samples (Jo, Son, Son, & Byun, 2003). Furthermore, the effect of green tea on *Clostridium perfringens* spore germination and outgrowth was evaluated in minced and cooked pork. The pork sample was treated with either green tea leaf powder with low total catechins or high total catechins. The results indicated that green tea with the higher level of catechins was able to reduce *C. perfringens* spore germination and outgrowth (Juneja, Bari, Inatsu, Kawamoto, & Friedman, 2007).

GTE incorporated into chitosan film was used for active packaging of pork sausages in order to enhance the shelf life, and it was observed that the pork wrapped with green tea incorporated film had lower lipid oxidation value and microbial growth. Therefore, enhanced antioxidant and anti-microbial properties of GTE incorporated film have great commercial values (Siripatrawan & Noipha, 2012). The addition of GTE along with probiotics to dry fermented pork loins showed no impact on sensory quality after storage (Neffe-Skocińska, Jaworska, Kołożyn-Krajewska, Dolatowski, & Jachacz-Jówko, 2015). GTE had significant dose-dependent antioxidant effect on the lipids and proteins of brine-injected packed pork chops (Jongberg, Tørngren, & Skibsted, 2018). Furthermore, when polyphenols isolated from green tea were included in the diet of growing pigs over a period of 5 weeks, the dietary inclusion did not have any impact on the vitamin E content of the serum, liver, lung and muscle, and on plasma antioxidant capacity and meat quality (Augustin et al., 2008). Green tea leaves have been used as an alternative to anti-microbial growth promoters in swine, and a significant growth promotion with no side effects and no possibility of spread of antibiotic-resistant pathogens was observed (Ohno et al., 2013).

3.3 | Goats

Goats fed with whole-crop oat silage along with green tea waste showed increased available crude protein and nitrogen retention, indicating the importance of green tea waste as a protein supplement (Kondo et al., 2004). The effects of green tea wastes on castrated male goats were evaluated using different parameters including appearance, water holding capacity, pH, protein content, proportions of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acid (PUFA), as well as ω-6 and ω-3 fatty acid contents (Ahmed, Lee, Mun, & Yang, 2015). The results revealed that the pH, water holding capacity and appearance of meat were not altered post-supplementation. MUFA, PUFA and ω-6 fatty acids contents increased in a linear fashion, whereas ω-3 fatty acids content increased in a quadratic fashion. Immune cell proliferation was also observed in green tea-supplemented goats, which indicates that green tea supplementation can improve the overall quality parameters of meat. Upon storage, the meat may develop off flavours due to the degradation of sulphur-bearing amino acids and fat oxidation. The antioxidant properties of green tea were evaluated to minimize the physiochemical changes in goat meat, and the results showed that 6,000 ppm of green tea prevented lipid oxidation in the goat meat (Rababah et al., 2011). Ahmed et al. (2015) revealed that with increasing dietary green tea by-products ranging between 0.5% and 2.0% of basal diet, an increase in average weight gain and feed intake ($p = .09$) was observed. An increase in dietary green tea by-products enhanced the amount of protein and reduced the crude fat as well as cholesterol content in goat meat. In addition, there was a linear and quadratic increase ($p \le .10$) in the n-6/n-3 fatty acids ratio (Ahmed et al., 2015). The addition of GTE to goat meat can reduce lipid oxidation during storage (Rababah et al., 2011).

3.4 | Poultry industry

Recent investigations demonstrate that supplementation of diets fed to broilers and layers with by-products of green tea can enhance production performance and reduce the amount of cholesterol in egg yolk and blood serum, besides the impact on egg quality. Supplementation of feeds with by-products derived from green tea minimizes the numbers of microflora in the caecum as a result of the anti-microbial effect of green tea (Khan, 2014). The poultry industry is being considered as one of the biggest industries after the textile industry, with an investment of about 200 billion rupees or more. The broiler industry is the best available means of producing proteins with high biological values to meet human demand for consumption. Poultry producers are using antibiotics as growth promoters in poultry diet to improve birds' productive performance. In Pakistan, the costs of growth promoters as feed additives for poultry ranges from 2 to 3 rupees/kg of diet. Through 2010 and 2011, poultry feed industry produced 4,900 million kg of feed and the expected price of growth promoters was approximately 1 billion rupees as reported by Bhatti (2011). Hence, in this scenario, herbs and their extracts can have useful potential applications with regards to their growth-promoting and multiple health benefits. The green tea leaf powder was able to maintain the freshness of chicken liver sausages by effectively retarding lipid oxidation (Choe, Kim, & Kim, 2019). Body weight, average daily weight gain, average daily feed intake and feed conversion ratio remained unaltered following the addition of GTE (125, 250, 500, 1,000 and 2000 mg/kg) to the diet of broiler chickens. GTE diet increased the antioxidant level in meat and also had immunostimulant activity with optimum inclusion at 125–500 mg/kg (Farahat, Abdallah, Abdel-Hamid, & Hernandez-Santana, 2016).

The use of GTE as the covering material of chicken burgers and chicken nuggets reduced the acrylamide level during pan frying and steam oven cooking without altering the sensory properties of the food material (Soncu & Kolsarici, 2017). Incorporation of edible coatings with GTE at 1% level significantly reduced fat oxidation resulting in a significant increase in the shelf life of chicken nuggets under refrigerated conditions (Kristam, Eswarapragada, Bandi, & Tumati, 2016). A lot of beneficial impacts on poultry have been observed with feeds supplemented with GTE. However, a report on gut microbiota which is suggestive of animal health indicates that inclusion of mulberry leaf powder in chicken diet increased the population of beneficial microbes like *Bacteroides*, *Prevotella* and *Megamonas*, while the inclusion of GTE enhanced the growth of potentially pathogenic *Gallibacterium* in the gut of chickens (Chen, Ni, & Li, 2019).

3.5 | Broilers chickens

In a study on broiler chickens, Biswas and Wakita (2001) added four levels of green tea powder (0.50%, 0.75%, 1.00% and 1.50%) to broiler diets and found that feed consumption and weight gain tended to decrease at a higher dose while feed conversion ratio improved. Likewise, Uuganbayar (2004) claimed that 1.00%–1.50% green tea supplementation in broiler diet reduced the body weight gain of chicks. Yang et al. (2003) conducted a trial to investigate the effect of graded levels of green tea by-product on the growth performance of broiler chickens, and the results showed an insignificant improvement in feed efficiency percentage. The authors reported that supplemented diets with powdered green tea by-product decreased the low-density lipoprotein (LDL) cholesterol level and increased high-density lipoprotein (HDL) and docosahexaenoic acid levels in the blood. Moreover, the cholesterol content of the meat reduced due to dietary supplementation with green tea by-product. Huang, Zhou, Wan, Wang, and Wan (2017) demonstrated that GTPs alter lipid metabolism in the livers of broiler chickens due to increased phosphorylation of AMP-activated protein kinase. The supplementation of L-theanine at an optimum level of 200 mg/kg in the diet resulted in the improvement of performance in broilers (Saeed et al., 2018). According to the author's knowledge, most of the previous studies in the literature were carried out in mice, honey bees and pigs but information on the effect of L-theanine in broiler chicken is scanty. These gaps owing to the lack of sufficient literature project that the advantages of green tea supplementation in broilers need to be addressed appropriately in the future.

Furthermore, Cao, Karasawa, and Guo (2005) demonstrated that weight gain, feed consumption and feeding efficiency was not enhanced at 28–42 days of age while viability was significantly improved by supplemental by-products derived from green tea production. Shomali, Najmeh, and Saeed (2012) studied the impact of powdered green tea (1.00%, 2.00% or 4.00%) on the growth of broiler and found insignificant differences in weight gain, feed consumption and feed efficiency. On the contrary, Sarker, Kim, and Yang (2010) reported a significant increase in body weight gain in broiler chickens during the finisher period at 0.50% level compared to 1.00% level of green tea powder. Guray et al. (2011) supplemented broiler diets with 0.10 or 0.20 g/kg extract (hydroalcoholic) of green tea and observed that the extract improved the values of live body weight, feed conversion, dressing percentage and carcass weight. The authors attributed the improved growth parameters to the physiological actions of GTE such as the regulation of the caecal microflora.

In a recent study, live body weight, feed intake and ileal digestibility of nutrients were not significantly affected by green tea supplement (10 g/kg diet) but plasma cholesterol and triglyceride levels were lowered in broiler chickens when compared with the control birds (Afsharmanesh & Sadaghi, 2014). In the same context, El-Deek, Al-Harthi, Osman, and Al-Jassas, & Nassar, R. (2012) concluded that the dietary addition of green tea (1.50 and 3.00 g/kg diet) did not affect the performance and meat quality of broilers. However, environmental emission and pollution through decreased excreted nitrogen were reduced with green treatments. Broiler chickens fed diets supplemented with graded concentrations of green extract tea (125, 250, 500, 1,000 and 2000 mg/kg) had improved antioxidant and immunostimulant characteristics. Furthermore, the antibody titre against vaccines for Newcastle disease virus increased in chicks fed diets supplemented with green tea (Farahat et al., 2016). So far, little work has been done on L- theanine with regards to poultry especially in broiler chickens which are excellent source of animal proteins. Therefore, there is need to explore the health benefit of L-theanine against stress problem in the poultry industry.

3.6 | Laying hens

Uuganbayar et al. (2005) examined the impact of dietary supplementation with green tea powder (up to 2.00%) in layers, and they found no significant effect on egg yield as well as on egg weight compared with the control. Similarly, Sadao and Yuko (2008) did not find any significant difference in the rate of egg yield, egg output or egg weight between laying hens consuming rations enriched with 1% green tea powder and the control, and increasing the concentration of green tea powder to 5% and 10% produced the lowest values. The same trend was observed by Biswas, Miyazaki, Nomura, and Wakita (2000) who noted that supplementing the layer rations with 0.6% Japanese green tea did not affect egg yield in a long-term trial. Ariana, Abdolhossein, Mohammad, and Rahman (2011) revealed that enriching layer rations with 1.5% powder of green tea as well as 0.5% extract of green tea did not affect egg mass, feed consumption and egg production. However, the addition of GTPs resulted in improved egg production, albumen quality and magnum morphology of Hy-Line Brown hens during the late laying period (Wang et al., 2018).

On the other hand, Al-Harthi (2004) showed that supplementation with 0.2% green tea resulted in better egg mass and production compared with the control. In a study by Uuganbayar, Shin, and Yang (2006) which involves the comparison of the impacts of two (1% or 2%) supplemental levels of Japanese, Chinese and Korean green tea on egg production in laying hens, the authors found that the egg yield of hens consuming diets supplemented with 1% or 2% green tea was significantly improved in comparison with the control group. Abdo, Hassan, Amal, and Shahinaz (2010) studied the influence of diet supplemented with the leaves of green tea (1%–5%) and the extract (0.50–2.50 L/100 kg diet) on layers, and the results showed enhancement in feed conversion, egg yield and egg output in the group fed with diet supplemented with 1.00% leaves of green tea when compared with the control. With regard to the production of quality egg, Biswas and Wakita (2001) observed that the albumen percentage and Haugh unit score improved with low level of powdered green tea (0.3%) as a dietary supplement. L-theanine could be helpful as a natural anti-stressor in the regions where environmental stress is a significant problem in the poultry industry, and this would create new idea for poultry nutritionists for its optimum usage in poultry diet.

3.7 | Dogs

The absorption of green tea catechins has been evaluated in beagle dogs. In urine, the presence of conjugated forms of EGCG and ECG indicated bile secretion, and EGC-glucuronide remains in the body for a longer period of time suggestive of an enterohepatic cycle (Mata-Bilbao et al., 2008). This study was helpful in the elucidation of the metabolism of green tea catechins in dogs. Another very important study conducted in dogs was related to the effects of chronic exposure to purified green tea components in the fasting stage in a 9-month experiment which was terminated in six and a half months due to mortality and morbidity. In this study, purified and standardized GTE was evaluated as a candidate anticancer agent in dogs. Low levels of RBC, haemoglobin, haematocrit, reticulocytosis, hematopoiesis and pigmented macrophages in liver, splenic erythropoiesis and bone marrow hyperplasia were the suggested reasons behind the mortality and morbidity (Kapetanovic et al., 2009). The results of the study indicate that purified and standardized GTE should not be taken in an empty stomach but with food or within an hour of food and the concentration of liver enzymes should be continuously monitored. GTPs protected nerve tissues from ischaemic damage for 1 month in a canine model; however, these immune suppression effects are not enough for allogeneic transplantation of peripheral nerves in the canine model (Nakayama et al., 2010). Levels of cortisol were within physiological limits in treated groups and comparable to those of the dogs in the control one (10–60 ng/ml L-theanine). There were no significant differences among the groups after treatment (Michelazzi et al., 2015).

3.8 | Fishes

Supplementation of green tea waste to basal diet by replacing wheat revealed positive results on the health of grass carp (*Ctenopharyngodon idellus*). The green tea waste improved the serum biochemical indices, serum antioxidant ability and non-specific immune response without having any adverse effect on the growth of grass carp (Zhou, Lin, Ji, & Yu, 2016). However, white tea-supplemented diet decreased the weight of gilthead sea bream juveniles (*Sparus aurata*) fishes. Supplementation with white tea also decreased feed intake and fish growth, and acted as a modulator of lipid metabolism (Pérez-Jiménez, Peres, Rubio, & Oliva-Teles, 2013). In concordance with the results of white tea; fishes fed with green tea also exhibited lower mean weight and feed efficiency rate. The expression of growth-related genes, *myf5* and *myf6*, also reduced.

3.9 | Mice, rat and fruit fly models

Some previous studies on mice such as that of Tamano et al. (2013) observed that when young rats were offered water supplemented with 0.3% L-theanine for three weeks after weaning and were exposed to water-immersion stress for 30 min, the serum CORT level was reduced in L-theanine administered rats compared to the control, even after exposure to stress. Similarly, Takeda et al. (2012) reported that drinking water containing 0.30% L-theanine when fed to young rats after birth caused a marked decrease in the serum CORT level. Lee, Park, Kim, Park, and Hong (2010) reported that oral administration of L-theanine decreases the levels of CORT, dopamine (DA), and noradrenaline (NA), but increases 5-HT content in the brain cortex, striatum and hippocampus of mice. Hence, L-theanine plays an important role in the secretion of neurotransmitters, hormones and immune cytokines. Moreover, L-theanine exerts a broad range of antioxidant activities and neuroprotective effects on mice cognitive impairments (Tian et al., 2013).

Recently, Jamwal and Kumar (2016) observed that when L-theanine was given to rat at 50 mg kg^{-1} day^{-1}, it preserved striatal neurotransmitters homeostasis and exerted neuroprotective effect, anti-inflammatory potential, antioxidant activity and free radical scavenging, which prevented neuron death. Kurihara, Shibahara, Arisaka, and Akiyama (2007) observed that the administration of L-cysteine and L-theanine via oral route can increase IgG level in the blood serum of mice. Another study by Yang et al. (2013) demonstrated a significant effect of L-theanine against stress via dry and wet starvation in male fruit flies. Li et al. (2016) observed that the administration of L-theanine at 400 mg/kg body weight daily in rat improved immune function by increasing the spleen weight and decreasing corticosterone level in the serum of rat. Green tea extended the lifespan of male Drosophila flies by inhibiting their reproductive potential, possibly by limiting iron uptake (Lopez et al., 2014).

A study conducted with EGCG, caffeine and L-theanine to evaluate the effect of these components on the survival of rat epididymal spermatozoa revealed that the three elements synergistically increased the survival of sperm up to 3 days (Dias, Alves, Casal, Silva, & Oliveira, 2016). L-theanine found in green tea could protect rat brain from the damage caused by aluminium (Sumathi, Shobana, Thangarajeswari, & Usha, 2015). EGCG isolated from green tea has the potential to control hyperglycaemia and attenuate diabetes by alleviating the formation of glycation end products (Sampath, Rashid, Sang, & Ahmedna, 2017).

Green tea consumption reduced oxidative stress, inflammation, and tissue damage in cigarette smoke-exposed albino rats (Al-Awaida, Akash, Aburubaiha, Talib, & Shehadeh, 2014). GTPs had an inhibitory effect on basal and stimulated testosterone production by rat Leydig cells in vitro (Figueiroa et al., 2009). In addition, they attenuated cyclosporin A (CsA)-induced renal injury partly through the induction of mitochondrial biogenesis (Rehman et al., 2013). Green tea activates lipolytic pathway and reduces adipose tissue and low-grade inflammation in mice fed a high-fat diet (Cunha et al., 2013). GTE is effective in suppressing LPS-induced retinal inflammation in rats probably through its strong antioxidant property and a receptor-mediated action on transcription factors that regulate the production of pro-inflammatory cytokines (Ren et al., 2018). GTE ameliorates iron overload-induced toxicity, apoptosis and oxidative stress in the liver of rats through the inhibition of hepatic iron accumulation, improvement of antioxidant capacity, downregulation of serum hepcidin and reduction in the release of apoptotic-related proteins (Al-Basher, 2019). It also showed angiogenesis promoting activity in diabetic wound healing in rat model wherein the functional role of circulating hypoxia-responsive microRNAs: miR-424, miR-210, miR-199a and miR-21 were prominent (Al-Rawaf, Gabr, & Alghadir, 2019). Green tea reduces the incidence of genitourinary tract tumours in Lobund-Wistar rat (O'Sullivan, Sheridan, Mulcahy, Tenniswood, & Morrissey, 2008), and GTE supplemented diet downregulated the genes associated with tissue inflammatory responses in mice (Cialdella-Kam et al., 2017). The functional efficacy of GTE as an anti-fibrotic agent in newborn rats has been attributed to the anti-free radical and anti-apoptotic inducing properties of its active constituents (Allam et al., 2017).

Maternal ingestion of green tea during pregnancy and nursing confers protection against transplacental carcinogenesis in mice (Castro et al., 2008). It is speculated that GTPs directly and indirectly suppress tumour cell proliferation and angiogenesis via human antigen (Hu) R-related pathways in bladder cancer in a mouse model (Matsuo et al., 2017). The protective effects of GTPs against high-fat-diet-induced non-alcoholic fatty liver disease in genetically obese Zucker fatty rats were mediated by a reduction in hepatic lipogenesis through the activation of the AMP-activated protein kinase pathway (Tan et al., 2017). Furthermore, fermented mixed tea containing green tea exhibited a preventive effect against the progression of non-alcoholic steatohepatitis (Omagari et al., 2018) and the combination of selenium and green tea was effective in suppressing colorectal cancer in rats (Hu et al., 2013).

4 | SIDE EFFECTS AND LIMITATIONS

Despite the health benefits and beneficial application of green tea as mentioned above in this review, possible negative impacts of green tea on fertility and animal reproduction have been noticed by other researchers. At a relatively high level (equivalent to five cups or more of green tea/day for 26 days), green tea extract caused impairment of functional and morphological status of rat testis, as well as inhibition of spermatogenesis (Chandra, Choudhury, Neela, & Sarkar, 2011; Das & Karmakar, 2015). In Indian, a study conducted by Das and Karmakar (2015) to evaluate the effect of leaf extract of green tea on reproductive performance of adult male rats showed that leaf extract of green tea is a potent herbal castrative agent when used in a specific level. Supplementation of green tea decreased serum level of testosterone and decreased sperm motility and count. The reduced level of testosterone may be attributed to decreased activity of steroidogenic enzymes (Das & Karmakar, 2015). Figueiroa et al. (2009) also showed that green tea extract polyphenols mainly epigallocatechin gallate has inhibitory impact on testosterone production of Leydig cell probably through PKA/PKC signalling pathway, in addition inhibition (direct or indirect) of both 17b-HSD and P450scc, which are required for synthesis of hormone (Figueiroa et al., 2009). Moreover, Chandra et al., recorded a significant decrease in serum testosterone level, epididymal sperm number in dose-dependent manner and testicular activities of steroidogenic enzyme in green tea extract administered group of animals after d 26 (Chandra et al., 2011). Abshenas and colleagues observed that green tea extract reversed the bad impacts of hyperthermia on semen indices. Scrotum of rat was exposed to 42°C in a water bath for 20 min in compared to 23°C in a control group, after which all the rats received green tea extract (500 and 750 mg/kg) administration orally for 49 consecutive days. Motility, concentration and hypo-osmotic swelling of semen decreased in all rats for the first 14 days (Abshenas, Babaei, Zare, Allahbakhshi, & Sharififar, 2012).

5 | CONCLUSION AND FUTURE PROSPECTS

The increasing demand for commercial green tea products due to the health-oriented lifestyle in our society has opened up new market opportunities. This has resulted in the development of green tea products exclusively for human consumption because such markets will fetch more income when compared to utilization in animal production units. The benefits of green tea are regularly being demonstrated, and hence, regular consumption of the tea as an alternative to other beverage drinks should be encouraged. This literature review highlights that green tea, L-theanine, and their products have various health-improving and growth-enhancing effects in animals including poultry. Based on the above findings, L-theanine could be utilized in the diets of pigs, goats, mice and poultry but at controlled quantity. Hitherto, there are limited investigations on L-theanine amino acid in the poultry industry, so its effects as a natural anti-stressor against environmental stress problem which is a major impediment in poultry needs to be investigated towards the improvement of the health status and productivity of birds. However, several areas are still unexplored but these areas may receive attention in the coming years. Conducting more researches with green tea and its bioactive compounds on different animal species, proper validation and clinical trials while exploiting the modern advances in biotechnology, nanotechnology and pharmacology would help in promoting and propagating the nutritional and medicinal values of green tea for enhanced production and improved health of animals.

ETHICAL APPROVAL

No ethical approval was required as this is a review article with no original research data.

ORCID

Mahmoud Alagawany https://orcid.org/0000-0002-8020-0971
Khan Sharun https://orcid.org/0000-0003-1040-3746

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