GINKGO BILOBA L. AND THE EFFECT OF ITS FERMENTED PRODUCTS ON PRODUCTION PHYSIOLOGY, BLOOD CHEMISTRY AND HISTOLOGY OF LIVESTOCK SPECIES: A REVIEW

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Abstract. Livestock play an important role in enhancing food security and livelihood of rural farmers, particularly in developing countries. However, the escalating cost of conventional feed resources such as maize and soybean, which account for the majority of livestock feed is a source of concern to farmers especially in the developing nations. This rising feed cost has compelled farmers and nutritionists to investigate the potential of leaves, fruits and seeds of underutilised tropical medicinal plants as an alternative. Ginkgo [*Ginkgo biloba* L; Family: Ginkgoaceae] one of such tropical medicinal plants is a multipurpose tree with several nutritional, medicinal, and industrial applications. Recent studies demonstrated that *G. biloba* and its fermented products are high in carbohydrates, minerals, vitamins, proteins, and essential amino acids. The plant is also high in bioactive compounds such as flavonoids, terpenoids, polyphenols, proanthocyanidins, and alkylphenolic acids, which may be responsible for their various medicinal properties. Research indicated that inclusion of moderate levels of fermented *G. biloba* products to livestock feed improved growth indices, product quality, blood chemistry and gut health via several modes of action. Knowledge and in-depth understanding of the nutritional and phytochemical composition of fermented *G. biloba* products as well as their effect on livestock productivity and health can help maximise their use in livestock nutrition, thus relieving the demand for conventional protein and energy concentrates.
Keywords: *Ginkgo biloba, alternative feedstuff, farm animals l, growth performance, physiological parameters, intestinal health*

Introduction

Maize and soybean are the main sources of energy and protein in livestock diets. However, the competition between humans and animals for these grains has led to an increase in their prices, and thus the costs of finished feeds. As a result, farmers have been compelled to seek for novel feedstuffs as alternative to grains in livestock diets. Several tropical medicinal plants produce leaves, fruits and seeds that can replace maize and soybean in livestock diets. *Ginkgo* (*G. biloba* L; Family: Ginkgoaceae), one of such tropical medicinal plants is high in nutrients and phytochemicals. It is a multi-faceted plant with several applications in the food, medical, and livestock industry. Interestingly, fresh or dried leaves and seeds of the ginkgo plant have nutritional and medicinal benefits (Singh et al., 2008). Ginkgo leaves contain polysaccharides, minerals, and amino acids (Yu et al., 2021) which are vital for animal wellbeing (Cao et al., 2012; Niu et al., 2017). Studies indicate that ginkgo possesses biological actions, including antioxidant,

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antimicrobial, anticancer, cardioprotection, and several others (Jiang et al., 2010; Sati and Joshi, 2011; Liu et al., 2013). The incorporation of ginkgo leaves into animal feed has been reported to reduce cholesterol content and prevent oxidative damage in farm animals (Bridi et al., 2001). The use of fermented ginkgo as a feed resource or supplement in poultry nutrition to improve performance and meat quality has also been reported (Yang et al., 2008; Cao et al., 2012; Zhang et al., 2015, 2020; Zhou et al., 2015; Kim et al., 2017; Niu et al., 2017, 2019). Ginkgo has also been reported to improve feed efficiency, nutrient digestibility, and meat quality in goats. However, ginkgo contains ginkgolic acids and some ANFs such as phytate, tannins, and oxalates (Nwosu et al., 2018), which may inhibit digestibility, nutrient utilisation, and well-being of animals when consumed in large quantities. The use of fermentation to enhance nutritional and functional properties of herbal products containing ANF elements has been reported (Sugiharto and Ranjitkar, 2019; Shi et al., 2021). There is an increasing body of knowledge on nutritional and phytochemical composition of ginkgo, as well as performance variables of animals fed with fermented ginkgo products (Cao et al., 2012; Zhang et al., 2015, 2020; Niu et al., 2017, 2019; Chen et al., 2021). However, these data are scattered in the literature, making it hard to use these findings in evidence-based decision-making. As a result, this paper reviewed published data on nutritional and phytochemical composition of *G. biloba*, as well as the impact of fermented *G. biloba* products on livestock performance and health in order to maximise their use in the livestock industry and reduced the pressure on conventional protein and energy concentrates.

Description and nutritional composition of *Ginkgo biloba*

Ginkgo biloba (common name: ginkgo, maidenhair-tree) has been used in folklore medicine for many years to treat several diseases and is also regarded as a living fossil. The name *Ginkgo* originates from the Japanese word *Yin–Kwo*, which means silver fruit, and the species name *biloba* is obtained from the bilobed shape of the leaves. Historically, ginkgo is indigenous to Southern China but is now cultivated in several tropical and subtropical regions due to its fast-growing ability, drought-resistant ability, tolerance of poor soil, good sprouting ability, and longevity. The plant can attain a height of 20 to 40 metres at maturity. *Ginkgo biloba* is referred locally as *obi gbogbo nse* by Yorubas in southwest Nigeria. The English name "maidenhair-tree" is derived from the shape and veins of its leaves, which are similar to those of the Maidenhair fern. *Ginkgo biloba* is one the known plant species and is taxonomically assigned to the family "Ginkgoaceae" and genus "Ginkgo" (*Table 1*). The plant has the following species: biloba, apodes, cranei, digitata, dissecta, gardneri, kinkgoidea, huolinhensis, huttonii, yimaensis, and adenoids, of which only biloba have gained global attention. Ginkgo has no close relative in the plant kingdom. Genomic studies revealed that Ginkgo is closer to the cycads than the conifers (Singh et al., 2008). Under favourable conditions, the mature plant can grow to a height of 20-40 metres. The leaf is feathery, fan-shaped, and greenish in colour, and has two distinct lobes with diverging veins. Most parts of the plant have therapeutic values and are used to cure several diseases in humans (Singh et al., 2008). Ginkgo seeds are high in phytonutrients, antioxidants, and neurotoxin (ginkgo-toxin), and should be consumed in small amounts.

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Table 1. *Taxonomy of Ginkgo biloba*

Kingdom	**Plantae**
Subkingdom	*Tracheobionta*
Division	*Spermatophyta*
Sub-division	*Cycadophytina*
Phylum	*Ginkgophyta*
Class	*Ginkgoopsida*
Order	*Ginkgoales*
Family	*Ginkgoaceae*
Genus	*Ginkgo*
Species	*G. biloba, G. apodes, G. cranei, G. digitata, G. dissecta, G. gardneri, G. kinkgoidea, G. huolinhensis, G. huttonii, G. yimaensis, G. adenoids,*
Common name	Ginkgo, Fossil tree, Maidenhair tree

The use of *Ginkgo biloba* products in animal feed is linked to their rich nutrient values and low ANF levels (Chen et al., 2021). Nutritional analyses show that ginkgo leaves are high in minerals, amino acids, vitamins, and bioactive agents (*Table 2*). The plant also contains carotenoids, such as α-carotene, γ-carotene, lutein, and Zeaxanthin (Singh et al., 2008), which may enhance yolk colour when added to the laying hen diet. Information on the nutrient value of ginkgo root and bark is still lacking in the literature. The ginkgo nuts are moderate in crude protein, amino acids, minerals, and vitamins (Pereira et al., 2013). However, the high levels of ginkgolic acids (e.g., ginkgotoxin glucoids) in the nut can result in vitamin B6 deficiency and other numerous side effects when consumed in large quantities. Traditional processing methods such as heat treatment can also reduce the level of toxins in the seeds. The *G. biloba* seed consists of a thin-layer nut that is used as food and medicine all over the world. Chemical analysis shows that *G. biloba* seeds contain 12.27 - 13.00 g/100 g protein, 6.00 g/100 g sucrose, 68.00 g/100 g starch, and 3.00 g/100 g fat (Singh et al., 2008; Pereira et al., 2013). The crude protein and total ash content of *G. biloba* leaf ranged between 6.65 – 18.50 g/100 g and 10.01 - 13.10 g/ 100 g, respectively (*Table 2*). Interestingly, Zou et al. (2019) found that microbial fermentation increased the crude protein content of *G. biloba* leaf by 64.9%. The differences in nutrient content of *G. biloba* products might be ascribed to differences in analytical methods, harvesting period, soil type, and processing techniques. *Table 2* indicates that *G. biloba* products are moderate in vitamins, minerals, and amino acids. Furthermore, ginkgo products contain about 18 amino acids, with the leaf having higher values than the seeds (Pereira et al., 2013; Zhou et al., 2019). The vitamin content of the leaf is also higher than the seeds. The mineral content of ginkgo leaves is lower than other plant sources like *Moringa oleifera* and *Teiferia occidentalis*, but higher than that *Vernomia amygdalina* and *Amaranthus spp* (Falowo et al., 2018). *Table 2* indicates that *G. biloba* leaf contains a high concentration of vitamin C (ascorbic acid) and vitamin E (tocopherol), which may be related to its antioxidative status. In livestock feed, calcium and phosphorus aid in bone development and regulation of acid-base balance, calcium is also important for eggshell formation, nerve transmission, and muscle activity. Potassium plays a vital role in protein and amino acid synthesis and electrolyte balance. *Ginkgo biloba* seeds are high in phosphorus and potassium and moderate in ascorbic acid (Pereira et al., 2013). Aside from the nutritional quality discussed above, *G. biloba* contained ANFs like phytate (0.56-0.59 μg/g), tannins (7.43 - 7.99 μg/g) and oxalates (0.65 μg/g) (Nwosu et al., 2018),

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which may reduce maximum utilisation of protein, minerals, and vitamins present in the feed when consumed in large amounts. Adeparusi (2001) reported that intake of diets high in tannins affects the bioavailability of protein and non-iron heme, thereby resulting in reduced iron and calcium uptake.

Table 2. *Nutritional values of G. biloba L. (per 100 g)*

Nutrient	Concentration range (Low - High)	
	Leaf	Seeds
Protein (g)	6.65[c] - 18.50[d]	12.27[b]
Fibre (g)	2.50[c]	-
Fat (g)	2.40[c] - 4.75[b]	-
Ash (g)	10.01[b] - 13.10[c]	-
Carbohydrates	59.70[c] – 72.98[b]	-
Na (mg)	1.65[e] - 2.34[c]	7.00[b]
K (mg)	4.33[c] -21.11[e]	510.00[b]
Ca (mg)	24.62[c] – 40.22[e]	2.00[b]
Cu (mg)	0.64[c] – 0.79[g]	0.27[b]
Fe (mg)	2.63[g] - 6.67[c]	1.00[b]
Zn (mg)	0.20[g] - 1.85[c]	0.34[b]
Mg (mg)	18.45[g] – 69.26[e]	27.00[b]
Na (mg)	1.76[g] - 2.34[c]	7.00[b]
P (mg)	4.90[c] – 32.65[e]	124.00[b]
Mn (mg)	0.63[c]	0.11[b]
Vitamin E (mg)	59.31[c]	-
Vitamin C (mg)	79.20[c]	15.00[b]
Vitamin B1 (mg)	1.53[c]	0.22[b]
Vitamin B2 (mg)	2.98[c]	0.09[b]
Vitamin B3 (mg)	2.44[c]	0.16[b]
Vitamin B6 (mg)	3.57[c]	0.33[b]
Vitamin B12	0.28[c]	
Serine (g)	1.51[d]	0.29[b]
Proline (g)	2.61[d]	0.34[b]
Glycine (g)	2.04[d]	0.23[b]
Leucine (g)	3.63[d]	0.31[b]
Glutamic acid (g)	7.67[d]	0.83[b]
Histidine (g)	1.51[d]	0.10[b]
Valine (g)	2.95[d]	0.28[b]
Phenylalanine (g)	1.80[d]	0.17[b]
Arginine (g)	4.86[d]	0.42[b]
Cystine (g)	0.16[d]	0.02[b]
Alanine (g)	2.91[d]	0.24[b]
Methionine (g)	0.75[d]	0.05[b]
Aspartic acid (g)	6.42[d]	0.54[b]
Lysine (g)	1.39[d]	0.20[b]
Isoleucine (g)	-	0.20[b]
Threonine (g)	2.29[d]	0.26[b]
Tryptophan (g)	-	0.07[b]
Tyrosine (g)	1.32[d]	0.06[b]

[a]Zhao et al. (2013); [b]Pereira et al. (2013); [c]Nwosu et al. (2018); [d]Zhou et al. (2019); [e]Koczka and Stefanovits-Bányai (2016); [g]Ibraheem et al. (2023)

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Ginkgo biloba as a source of bioactive compounds and antioxidants

The *G. biloba* plant contains a plethora of important bioactive components (*Table 3*), also known as secondary metabolites or phytochemicals (Singh et al., 2008; Leistner and Drewke, 2009; Liu et al., 2021). *Ginkgo biloba* contains 6% terpenoids, 5% – 24% flavonoid glycosides, 10% organic acids, and other compounds with well-documented pharmacological effects (Chan et al., 2007; van Beek and Montoro, 2009; Liu et al., 2021). The flavonoid component of *G. biloba* plant consists of three flavonols: isorhamnetin, quercetin, and kaempferol. Aspects of these phytochemicals identified via several extraction and analytical methods have antioxidant, antilipidemic, anti-cancer, antimicrobial, antiviral, and hepatoprotective properties. Plants essentially produced these phytochemicals in response to stress due to environment, insect attacks, as well as ultra-violet radiations (Khoddami et al., 2013). A list of different bioactive compounds extracted from various parts of *G. biloba* plant has been documented (*Table 3*). *Ginkgo biloba* contains natural antioxidants such as tocopherols, ascorbic acid, carotenes, flavonoids, and other phenolic compounds. Oxidation has been linked to the emergence of several chronic degenerative diseases (Benzie, 2000). *Ginkgo biloba* contains several unique antioxidant compounds (Jiao et al., 2016; Wang et al., 2016) and have shown to scavenge 2, 2-azinobis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radicals. The major bioactive compounds believed to contribute to *G. biloba's* antioxidant potential are flavonoids, bioflavonoids, and terpenoids. An earlier study by Chen et al. (2012) indicates that *G. biloba* exocarp is a more potent antioxidant than vitamin C. These findings imply that *G. biloba* products are excellent sources of antioxidants and can be added to livestock feed to prevent oxidative stress and improve animal productivity and product quality. The antioxidant property of ginkgo products is believed to account for its hepatoprotective properties.

Constituents of fermented *G. biloba*

Fermentation is an important technique for creating feedstuffs with health-enhancing properties (Ng et al., 2011). It is also one method used to enrich tropical plants with enzymes, growth factors, and essential nutrients (Ng et al., 2011; Zhang et al., 2015). One important advantage of fermentation over other processing methods is that the technology is simple and cheap. Analytical studies indicate that *G. biloba* leaves are rich in essential nutrients and phytochemicals (van Beek and Montoro, 2009; Li et al., 2012). Evidence exists that flavonoid aglycones are more readily absorbed in the digestive tract after fermentation (Izumi et al., 2000). Also, Vattem and Shetty (2003) noted that cellulosic enzymes produced by microbes during fermentation hydrolyse flavonoid glucosides, a bitter substance in ginkgo leaves to free aglycones which are known for their higher bioactivities. Zhang et al. (2012) discovered that fermentation of *G. biloba* leaves with *Aspergillus niger* for 48 h reduced total flavonoids and ginkgolic acid levels by 3 and 97%, respectively, and increased their total amino acids, total polysaccharides, and crude protein content by 21, 95, and 73%, respectively. In a similar experiment, Cao et al. (2012) found that the total flavonoid level of *G. biloba* leaves was reduced by 3%, while their total polysaccharides, total amino acids, and total crude protein contents were increased by 51, 21, and 73%, respectively after fermentation. The reported increase in crude protein content after fermentation may be due to an increase in microbial mass turnover.

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Table 3. *Bioactive components in various parts of G. biloba*

Components
Ginkgotoxin
Monoterpenes: cymene, isopropyl-phenol, thymol, ionone
Diterpenes: Ginkgolide A, B, C, J, M, K and L
6-Hydroxykynurenic acid
Didehydro (10′,11′), Me ester, 2-Heptadecyl-6-hydroxybenzoic acid
Z-2,4-Dihydroxy-6-(8-pentadecenyl) benzoic acid
Ginkgoic acid
Hydroginkgolic acid
6-(10-Heptadecenyl) salicylic acid
6-Hydroxy-2-(10-hydroxy-11-pentadecenyl) benzoic acid
6-Hydroxy-2-(11-hydroxy-9-pentadecenyl) benzoic acid
6-Hydroxy-2-(12-hydroxy-13-heptadecenyl) benzoic acid
6-Hydroxy-2-(13-hydroxy-11-heptadecenyl) benzoic acid
Merulinic acid C
Tridecylsalicylic acid
8-(5-Carboxy-2-methoxyphenyl)−5,7-dihydroxy-4′-methoxyflavone
Ginkgol
Sesquiterpenes: Bilobalide, bilobanone, elemol, fudesmol (18
Heptadecenyl phenol
Irisresorcinol
Tridecylphenol
Amentoflavone
Bilobetin
Flavone
Ginkgetin
Ginkgetin 7′’-glucoside
Isoginkgetin, Isoginkgetin 7-glucoside
Mearnsetin 3-rutinoside
Methoxybilobetin
Penta (3′,4′,5,5′,7)-Me ether, 3,3′,4,4′,5,5′,7-Heptahydroxyflavan
Quercetin 3-(2-glucosylrhamnoside
Bilobalide A
Bilobanol
Bilobanone
Bisaboladien (2,7)− 9-one
Bisaboladiene (3,7)− 2,8-dione
Dihydro (10,11), 2,7,10-Bisabolatrien-9-one
Dihydrophaseic acid (9E)
Dihydro (3,4)− 8-hydroxy-3-tridecyl-1H-2-benzopyran-1-one
Dihydroxy (2,3)− 7-megastigmen-9-one
Di-Me ether (3,3′), 1,2-Bis(3,4-dihydroxyphenyl)ethylene
Eicosadienoic acid (11,14)
Ginkgool
Globosterol
Sciadonic acid

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Components
Shikimic acid
Urolignoside
Kaempferol
Quercetin
Myricetin
Apigenin
Isorhamnetin
Luteolin
Catechin–catechin
Epicatechin–catechin
Epigallocatechin–catechin
Gallocatechin–catechin

Adapted from Bedir et al. (2002); Singh et al. (2008); Deguchi et al. (2014); Ma et al. (2016); Menezes and Diederich (2021); Song et al. (2021); Samec et al. (2022); Akaberi et al. (2023)

The slight decrease in total flavonoid content after fermentation with *Aspergillus niger* indicates the *A. niger*'s ability to produce β-glucosidase that hydrolyses flavonoid to aglycones, which seem to possess higher bioactivity than flavonoid glycones (Hsu and Chiang, 2009). Also, the observed increase in total polysaccharide level may be related to the reduced carbohydrate content after fermentation (Hong et al., 2004).

Influence of fermented *G. biloba* on growth performance of livestock

A recent feeding trial by Chen et al. (2021) showed that replacement of 18% alfalfa hay pellet in goat diet with fermented G. biloba residues (FGBR) increased feed intake and body weight gain (BWG) by 12 and 20%, and decreased feeding cost and feed conversion ratio (FCR) by 8 and 7% as compared with the control diet, respectively. Chen et al. (2021) also revealed that FGBR enhanced dry matter and neutral detergent fiber digestibility in goats. Similarly, Niu et al. (2017) showed that BWG and feed intake by supplementation of 0.35% fermented G. biloba leaf (FGBL) in broiler diet were increased by 6% and 5%, respectively when compared to the control ration. In converse, feed intake, and FCR were not improved in broiler chickens fed 0.35% and 0.70% unfermented *G. biloba* leaf for 42 days (Cao et al., 2012). The same authors noticed reduced FCR (superior) and abdominal fat content in broiler chickens offered an FGBL-supplemented diet for 42 days. The reduced abdominal fat content may be related to cholesterol lowering potential of *G. biloba* products (Singh et al., 2008), which may lead to acceptance of the meat by consumers. Zhou et al. (2015) found that growing pigs fed FGBR had better BWG and FCR than the control. The improved growth performance in FGBL and FGBR could be attributed to the enhanced quality of the diet due to the ability of fermentation to increase the concentration of total amino acids, total polysaccharides, and crude protein and reduce the level of ginkgolic acids (Zhang et al., 2012). This could also be attributed to the positive effect of *G. biloba* on intestinal morphology. However, more research is required to determine the precise mechanism by which ginkgo products increase growth performance due to the complex nature of their bioactive constituents.

Zhang et al. (2012) and Niu et al. (2017) noticed improved growth performance parameters of broiler chickens on dietary FGBL supplementation alluding that fermented

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herbal products could increase growth performance in animals (Ao et al., 2011; Kim et al., 2012). This supports the view that fermentation increases the nutritional and functional properties of *G. biloba* leaves (Cao et al., 2012; Zhang et al., 2015; Zou et al., 2019). These findings indicate that FGBL could be a potent feed additive for broiler chicken production. In addition, dietary supplementation of FGBL (5 and 10%) in broiler chicken feed suggested that BWG and feed intake were enhanced during the starter and finisher periods compared to the control diet (Kim et al., 2017). In a similar experiment, Yu et al. (2015) noticed no effect of dietary ginkgo leaf supplementation at 0.35% on feed intake and BWG in broiler chickens. Zhou et al. (2015) investigated the impact of dietary FGBR on weaned piglet growth traits and discovered that FGBR can be added to the diet of weaned piglets to boost growth performance. This is similar to the finding of Kim et al. (2016) with the feeding of FGBL to broiler chickens at 0.2 and 0.4% for 35 days. The enhanced growth performance in animals fed fermented ginkgo products could be attributed to the synergistic effect of polysaccharides, amino acids, proteins, and flavonoids, which have been reported to regulate growth performance by stimulating the secretion of growth hormones (GH), insulin-like growth factor-I (IGF-I) IGF-1 and increasing the excitability of hypothalamic-pituitary-adrenal (HPA) axis (Muqier et al., 2017).

Regarding *G. biloba* essential oil (GBEO), El-Kasrawy et al. (2023) reported higher feed intake, live body weight, and BWG in broiler chickens administered a low dose of GBEO (0.25 cm/L) via drinking water. However, at the administration of a higher dose (0.5 cm/L) in the drinking water, the authors noticed a lower feed intake, live body weight, and BWG compared to the control diet. This implies that a higher dose of GBEO supplementation has a harmful impact on broiler chicken performance owing to the presence of ginkgolic acid, a toxic substance reported to have cytotoxic and allergic properties (Yu et al., 2015). Besides, the observed poor performance in the group that received a higher dose of GBEO can be attributed to the presence of ANFs, such as tannins, oxalate, and phytate (Nwosu et al., 2018) which can inhibit the bioavailability of certain minerals and reduce protein digestibility (Falowo et al., 2018). These results are not in agreement with Yu et al. (2015), who discovered that the inclusion of fermented ginkgo leaf at 0.35% in broiler diet did not affect feed intake and BWG. Disparities in the results between studies could be linked to differences in the presentation form (extract, essential oil or powder) and administration route (feed or water).

Effect of fermented *G. biloba* on blood chemistry of livestock

Ginkgo biloba, like other investigated tropical plant products (Manyelo et al., 2022; Ogbuewu and Mbajiorgu, 2023), is high in nutrients and phytochemicals, making it an excellent source of feedstuff and additive. The processed leaves of *G. biloba* are easily consumed by goats and chickens as a component of the feed. There is scanty information on the effect of *G. biloba* on livestock performance and product quality in the literature. However, Haimen white goats fed fermented *G. biloba* products had improved physiological parameters and meat quality. Physiological parameters are used as an index of health status and nutrient metabolism in farm animals (Wei, 2020; Maoba et al., 2021). The replacement of alfalfa hay pellet with FGBR at 6, 12, 18, and 24% in the ruminant feed did not affect the serum biochemical constituents of goats (Chen et al., 2021). In converse, the substitution of wheat with FGBR at 5, 10, and 15% increased total iron, total protein, albumin, and glucose content in growing pigs while reducing the

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concentration of urea nitrogen (Zhou et al., 2015). Higher serum protein and albumin were found in broilers fed a basal diet supplemented with GBEO at 0.25 cm/L than those that received 0.5 cm/L and diet without GBEO supplementation (El-Kasrawy et al., 2023). Similar results have been observed in fish administered *G. biloba* leaf extract at 0.50 to 4.00 g/kg (Tan et al., 2018). The significantly higher protein and lower urea nitrogen value in pigs fed FGBR diets suggests that treatment diets are higher in protein than the control diet (Kim et al., 2013). These findings are in harmony with earlier studies which showed that fermented herbal products can enhance blood metabolites in growing pigs (Lee et al., 2009).

Serum lipids are used as an index of lipid metabolism in animals (El-Katcha et al., 2021). Oral administration of GBEO at 0.25 and 0.5 cm/L increased serum cholesterol and low-density lipoprotein cholesterol (LDL-C) levels in a dose-related manner in broiler chickens (El-Kasrawy et al., 2023), suggesting that higher dose of GBEO supplementation could have a negative impact on lipid metabolism in broiler chickens. In contrast, Zhou et al. (2015) established that substitution of wheat with FGBR at 5, 10, and 15% in pig diets decreased blood cholesterol and triglyceride content. In another study, Cao et al. (2012) and Zhao et al. (2013) reported decreased serum triglycerides and LDL-C and increased high-density lipoprotein cholesterol (HDL-C) in broiler chickens fed FGBL due to high levels of flavonoids in ginkgo leaf that could modulate lipid metabolism and prevent lipid deposition (Wei et al., 2014). The mechanism by which FGBR lowers blood lipid content is not clear. However, this decrease could be explained by the ability of flavonoids, the main bioactive ingredient in the ginkgo plant to form insoluble complexes with cholesterol in the digesta and prevent intestinal absorption of cholesterol (Rao and Gurfinkel, 2000; Velasco et al., 2010). This could also be due to the potential of flavonoids to upregulate hepatic genes for β-oxidation and downregulate genes for fatty acid production (Aoki et al., 2007).

Oh et al. (2016) found ginkgo fruit extract reduced ruminal methane and ammonia production, and increased propionate production in cow rumen. This change could be attributed to the selective inhibition of rumen microbes through the surfactant action of the alkylphenols contained in ginkgo fruit. Chen et al. (2021) observed no difference in rumen pH and ammonia nitrogen (NH3-N) levels of goats fed graded levels of FGBR. Furthermore, FGBR increased the acetate and acetate: propionate values in the rumen while decreasing the propionate value. These observations suggest that FGBR has the potential to improve rumen fermentation while having no negative consequences on rumen health. Dietary FGBL supplementation did not affect serum immunoglobulin G (IgG) in broiler chickens (Kim et al., 2016). In contrast, broiler chickens fed rations supplemented with FGBL had significantly higher serum immunoglobulins A and M (IgA and IgM) than the control (Kim et al., 2016). Similarly, Chen et al. (2021) found that Haimen goats fed FGBR as a substitute for alfalfa hay pellets had increased serum IgG and reduced interleukin 4 levels. In another study, Xiao (2008) noticed that oral administration of *G. biloba* extract increased the concentrations of blood globulin and IgG in broiler chickens, implying that *G. biloba* extract can improve immunity in farm animals. This immune-stimulating effect of ginkgo products could be attributed to their terpenes, flavonoids, and polysaccharide levels shown to stimulate the release of cytokine and the production of lymphocytes (Zhao et al., 2011).

Higher levels of glutathione peroxidase (GSH-Px) and superoxide dismutase (SOD) in the blood reflect the body’s ability to scavenge free radicals. Superoxide dismutase assists in the conversion of superoxide anion radicals to hydrogen and hydrogen peroxide. Chen

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et al. (2021) demonstrated that FGBR decreased the synthesis of serum malondialdehyde (MDA) and increased the expression of serum GSH-Px and SOD in goats. In a similar study, Zhou et al. (2015) showed that growing pigs fed FGBR had reduced serum MDA and increased serum GSH-Px and SOD levels. Additionally, Cao et al. (2012) found enhanced antioxidative status of broiler chickens fed FGBL. In a recent study, El-Kasrawy et al. (2023) found that oral administration of GBEO at 0.25 cm/L upregulated the expression of antioxidant genes in the liver. The authors also found downregulation of antioxidant genes in broiler chickens administered GBEO at the level 0.5 cm/L. These findings suggest that a low dose of GBEO can increase the antioxidative status of broiler chickens by upregulating the expression of antioxidant genes (Tan et al., 2018). A similar finding has been observed in rats administered ginkgo leaf through parental solution for 15 days (Zhao et al., 2011). Also, Niu et al. (2019) established that FGBL supplementation improved the expression of serum antioxidant enzymes [SOD, GSH-PX, and total antioxidant capacity (TAOC)] in broiler chickens.

Effect of fermented *G. biloba* on gut histology of livestock

The superior FCR in animals on dietary fermented ginkgo supplementation may be due to improvement in intestinal health. The intestine is the principal site for nutrient uptake and its outer layer can give vital information on the health of the intestine. Changes in intestinal histology such as shorter villi and deeper crypts indicate the occurrence of toxic substances in the feed (Xu et al., 2002). Shorter villi lead to a reduction in the surface area for nutrient uptake, while a large crypt connotes fast tissue turnover and high demand for new tissue (Yu et al., 2015). Shorter villi and larger crypts can result in low nutrient uptake and poor growth performance. Yu et al. (2015) observed improved villus height (VH), crypt depth (CD), and VH: CD values of the duodenum, ileum, and jejunum of broiler chicken on dietary FGBL supplementation. This suggests that FGBL improved the absorptive function of the intestine in broiler chickens. The increased BWG and superior FCR in animals fed ginkgo are consistent with improvements in intestinal histology, implying that fermented ginkgo improves growth performance by increasing absorptive functions. In the small intestine, the expression of mucosal alkaline phosphatase (AKP) enzyme function increases as intestinal cells mature and migrate toward the tip of the villi (Zhang et al., 2012). Alkaline phosphatase is an enzyme that aids in the hydrolysis of phosphate esters in a basic medium as well as the digestive process. Pancreatic and intestinal digestive enzymes are also essential for digestion and assimilation of nutrients. Zhang et al. (2012) noted that broiler chickens fed 0.35 – 0.4% and 0.7 - 1.0% FGBL in the starter and finisher phase, respectively showed increased pancreatic, intestinal, and mucosal AKP enzyme activities than the control and birds fed 0.35 and 0.7% unfermented GBL, suggesting that FGBL bioactive compounds improve intestinal morphology by increasing the activities of intestinal enzymes.

A recent feeding experiment by El-Kasrawy et al. (2023) established that jejunum VH and growth performance of broiler chickens were positively influenced by administration of GBEO at 0.25 cm/L compared to broiler chickens administered 0 and 0.5 cm GBEO/L. The observed increase in jejunum VH implies that broiler chickens administered GBEO at 0.25 cm/L had enhanced absorptive function, which could explain the increased growth performance of broiler chickens in this group. On the other hand, Yu et al. (2015) and Zhang et al. (2015) found improved absorptive capacity of chickens fed fermented ginkgo leaf products. Similarly, Zhang et al. (2012) found that intestinal histological parameters

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were positively influenced in broiler chickens fed FGBL at 0.5% (1-21 d) and 1.0% (22-42 d). Fermented G. biloba leaf supplementation at 0.2 and 0.4% significantly reduced the population of *E coli* in the caecum of broiler chickens (Kim et al., 2016). In contrast, the caecal composition of *Lactobacillus spp*., yeast, and Salmonella was unaffected by FGBL supplementation. Zhao et al. (2013) found similar results in laying hens fed FGBL-based diets. The reduced pathogenic *E coli* load in the caeca of broiler chickens fed FGBL could be attributed to the presence of flavonoids and organic acids in ginkgo reported to have an antimicrobial effect (Akaberi et al., 2023). There is scanty published data on the impact of fermented and unfermented *G. biloba* products on the gut microbiology of livestock, and more research should be channeled to this area.

Impact of fermented *G. biloba* on product quality of livestock

Slaughter performance indicates the ability of animals to convert feed to muscles (meat). Supplementation of 0.35 and 0.45% of FGBL in the broiler diet increased carcass yield and cut-part (i.e., breast and thigh) weights. In a similar study, Yang et al. (2008) reported improved carcass yield in broiler chickens administered FGBL extract at 10 g/kg. The improved carcass yield and cut-part weights in animals fed FGBL could be ascribed to the positive influence of the bioactive compounds in the ginkgo plant on nutrient absorption and metabolism.

Cooking loss, pH, colour, and water holding capacity (WHC) are critical physicochemical parameters used to determine the shelf life of meat (Ahmed et al., 2015). There is a positive relationship between meat colour and pH, and they are used to determine consumer acceptability. Meat colour [redness (a*), lightness (L*), and yellowness (b*)] which is assessed objectively by colorimetric measurement is related to myoglobin and meat structure. Water loss minimises the nutrient quality of meat by removing some vital nutrients in the exudates, resulting in drier and tougher meat (Pelicano et al., 2003). A recent study by Chen et al. (2021) showed that the substitution of alfalfa hay pellet with 18% FGBR in goat diet improved a* value, but had no impact on cooking loss, pH, shear force, L* and b* values. The increased a* value could be attributed to the antioxidant ability of bioactive compounds in FGBR, which prevent the oxidation of oxymyoglobin to metmyoglobin. In contrast to the recent findings of Chen et al. (2021), other researchers found that FGBL improved WHC (drip loss and cooking loss) in broiler meat (Cao et al., 2012; Niu et al., 2017). This variation could be attributed to differences in animal species, the quantity, and part of the ginkgo plant added to the feed. According to Allen et al. (1998), the L* value is an indicator of the meat’s freshness and has direct influences on the consumer’s final purchase decision. The inclusion of 0.35% FGBL reduced the L∗ value in breast meat (Niu et al., 2017). The high carotenoids in ginkgo leaves (Singh et al., 2008) may explain why 0.35% FGBL supplementation resulted in lighter breast meat colour.

Meats are high in polyunsaturated fatty acids (PUFA), making them vulnerable to free radical attack (Asghar et al., 1990). Free radicals are generated as a result of lipid oxidation, which can result in the oxidation of meat pigments and the production of rancid odours and flavours. FGBL reduced MDA, which is employed to explore the degree of lipid peroxidation and increased the expression of total antioxidant capacity (TOAC) and SOD levels in the meat (Cao et al., 2012). This implies that ginkgo supplementation enhanced the antioxidative status of chicken meat by modulating the cellular free radical / antioxidant balance. The authors also found that FGBL improved breast muscle quality

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(i.e., colour, cooking loss, drip loss, and shear force) in broiler chickens, while unfermented ginkgo leaves do not affect breast muscle quality. In agreement with the results of Cao et al. (2012), Niu et al. (2017) noticed increased TAOC and SOD and reduced MDA levels in the thigh and breast meat of broiler chickens fed FGBL at 0.35, 0.45 and 0.55%. The increased antioxidant enzyme activities of meats from broilers fed fermented ginkgo products could be related to the phytochemicals contained in the plant, like flavonoids and terpenoids, found to possess antioxidant properties (Sati et al., 2019).

Regarding FGBL, Cao et al. (2012) found decreased total saturated fatty acid (SFA) value in breast meat which is basically due to the significant reduction in the value of palmitic acid and stearic acid. Conversely, FGBL improved total polyunsaturated fatty acids (PUFA) due to a significant increase in linoleic acid, linolenic acid, and arachidonic acid. This observation supported the earlier results that FGBL enhanced the endogenous antioxidant system of pigs (Zhou et al., 2015) and small ruminants (Chen et al., 2021). There exists a strong relationship between cardiovascular disease (CVD) and the consumption of SFA and total cholesterol-rich foods (Zhou et al., 2009). This implies that intake of meats from broiler chickens fed FGBL may reduce the incidence of CVD. Kim et al. (2017) also noticed decreased SFA and monounsaturated fatty acids (MUFA) and increased n-3 PUFA in the breast and thigh meat of broiler chickens fed FGBL. The changes in SFA and PUFA in breast and thigh meat could be attributed to the action of secondary metabolites in the *G. biloba* plant might influence the activity of the 9-desaturase enzyme, the key enzyme associated with the conversion and elevation-diminution process of fatty acid (Kamboh and Zhu, 2013). There is growing interest by consumers for meats that are rich in n-3 PUFA to reduce the incidence of CVD. The inclusion of FGBL increased the concentration of eicosapentaenoic acid and docosahexaenoic acids in broiler meat which are the two most important n-3 fatty acids in animal nutrition.

Zhao et al. (2013) revealed the capability of dietary FGBL supplementation to enhance FCR, laying rate, and egg quality in layers. The authors also found reduced egg-yolk cholesterol levels in laying hens fed FGBL-supplemented diets. The lower egg-yolk cholesterol content of layers fed FGBL supplemented feed compared to those fed control diet could be attributed to a decrease in circulating serum triglyceride level (Gonzalez-Esquerra and Leeson, 2000). Dietary FGBL supplementation influenced the fatty acids composition of egg yolk (Zhao et al., 2013). A similar observation has been recorded in meat from broiler chickens fed FGBL (Cao et al., 2012). Also, Zhao et al. (2013) noticed a decreased total SFA and increased total PUFA level in egg yolk in response to FGBL supplementation. The lower total SFA level in egg-yolk of FGBL-fed layers suggests that eating these eggs reduces the incidences of CVD in humans. This review also showed that there is little or no published information on the impact of dietary fermented *G. biloba* supplementation on milk production, laying rates, and quality, suggesting that more studies should be conducted in this area.

Conclusion and future research direction

This review demonstrated that *Ginkgo biloba* L. and its fermented products contain essential nutrients, bioactive compounds, and anti-physiological agents, and their inclusion in livestock feed at smaller amount improved growth performance, blood chemistry, gut health and product quality. However, more innovative methods for processing Ginkgo biloba are needed to increase its inclusion level in livestock diets.

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Moreso, feeding experiments on the impact of the *Ginkgo biloba* on productivity, health and product quality of duck, turkey, rabbits, pigs, sheep and cattle would be interesting as little or no research has been done and published in this area. There is also scanty work on haematology, gut microbiota composition and economics of production of livestock species fed ginkgo products; therefore, future study should focus on these areas

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