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USE OF KOMBUCHA AS FEED ADDITIVE IN ANIMAL NUTRITION

USO DE KOMBUCHA COMO ADITIVO ALIMENTAR NA NUTRIÇÃO ANIMAL

USO DE KOMBUCHA COMO ADITIVO ALIMENTARIO EN NUTRICIÓN ANIMAL

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ABSTRACT

The growing demand for sustainable and natural alternatives to antibiotic growth promoters in animal nutrition has led to the exploration of functional additives. Kombucha is a fermented beverage rich in bioactive compounds, including organic acids, polyphenols, vitamins, and enzymes, produced by a symbiotic culture of bacteria and yeasts (SCOBY). This review analyzed 19 scientific studies conducted between 2005 and 2025 that investigated the effects of kombucha supplementation in various animal species. The findings indicate that kombucha can enhance feed efficiency, weight gain, nutrient digestibility, and immune response without adverse effects. Its use has also been associated with hypocholesterolemic, antimicrobial, antioxidant, and antiparasitic activities. However, the literature is still limited and heterogeneous regarding species studied, dosage, and administration methods. Further research is needed to standardize protocols and evaluate long-term impacts. Overall, kombucha emerges as a promising natural feed additive with the potential to improve animal health, performance, and sustainability in livestock production.

KEYWORDS: *Antimicrobial. Antioxidant. Nutrient digestibility. Feed efficiency. Immune response.*

RESUMO

A crescente demanda por alternativas sustentáveis e naturais aos promotores de crescimento antibióticos na nutrição animal tem levado à exploração de aditivos funcionais. A kombucha é uma bebida fermentada rica em compostos bioativos, incluindo ácidos orgânicos, polifenóis, vitaminas e enzimas, produzida por uma cultura simbiótica de bactérias e leveduras (SCOBY). Esta revisão analisou 19 estudos científicos conduzidos entre 2005 e 2025 que investigaram os efeitos da suplementação com kombucha em diferentes espécies animais. Os resultados indicam que a kombucha pode melhorar a eficiência alimentar, o ganho de peso, a digestibilidade dos nutrientes e a resposta imunológica, sem efeitos adversos. Seu uso também tem sido associado a atividades hipocolesterolêmicas, antimicrobianas, antioxidantes e antiparasitárias. No entanto, a literatura ainda é limitada e heterogênea quanto às espécies estudadas, dosagens e métodos de administração. Mais pesquisas são necessárias para padronizar protocolos e avaliar os impactos em longo prazo. De modo geral, a kombucha surge como um promissor aditivo alimentar natural, com potencial para melhorar a saúde animal, o desempenho produtivo e a sustentabilidade na produção pecuária.

PALAVRAS-CHAVE: Antimicrobiano. Antioxidante. Digestibilidade de nutrientes. Eficiência alimentar. Resposta imune.

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RESUMEN
La creciente demanda de alternativas sostenibles y naturales a los promotores de crecimiento antibióticos en la nutrición animal ha impulsado la búsqueda de aditivos funcionales. La kombucha es una bebida fermentada rica en compuestos bioactivos, entre ellos ácidos orgánicos, polifenoles, vitaminas y enzimas, producida mediante un cultivo simbiótico de bacterias y levaduras (SCOBY). Esta revisión analizó 19 estudios científicos publicados entre 2005 y 2025 que investigaron los efectos de la suplementación con kombucha en diferentes especies animales. Los resultados indican que la kombucha puede mejorar la eficiencia alimenticia, la ganancia de peso, la digestibilidad de los nutrientes y la respuesta inmunitaria, sin efectos adversos aparentes. Asimismo, su uso se ha asociado con actividades hipocolesterolémicas, antimicrobianas, antioxidantes y antiparasitarias. Sin embargo, la literatura disponible sigue siendo limitada y heterogénea en cuanto a las especies estudiadas, las dosis utilizadas y los métodos de administración. Se requieren más investigaciones para estandarizar los protocolos y evaluar sus efectos a largo plazo. En conjunto, la kombucha se perfila como un aditivo alimentario natural prometedor, con potencial para mejorar la salud animal, el rendimiento productivo y la sostenibilidad de los sistemas de producción pecuaria.

PALABRAS CLAVE*: Antimicrobiano. Antioxidante. Digestibilidad de nutrientes. Eficiencia alimenticia. Respuesta inmunitaria.*

1. INTRODUCTION

Animal production has emerged as one of the most dynamic sectors of agribusiness. With this growth, the need for constant adaptation in the field of animal nutrition has become evident, driving the search for strategies that not only enhance productivity but also ensure product quality and the sustainability of production systems (Placha *et al.*, 2022). In this context, animal nutrition stands out as a key pillar for maximizing zootechnical performance and promoting animal health and welfare.

The incorporation of feed additives into animal diets has become a fundamental strategy for optimizing feed conversion, reducing disease incidence, and enhancing animal growth (van der Aar *et al.*, 2017). Among zootechnical additives, growth promoters are widely used in animal production. This group includes substances such as antibiotics, probiotics, prebiotics, organic acids, phytogenics, and ionophores, which act through various mechanisms. Their effects include modulation of the gut microbiota, improved nutrient digestibility, and stimulation of muscle growth, resulting in greater weight gain and feed efficiency (Silva *et al.*, 2020).

However, the misuse of antibiotics as growth promoters has raised increasing concern due to the risk of antimicrobial resistance development, posing a threat to both animal and human health (Ayalew *et al.*, 2022). This scenario has driven the search for natural and sustainable alternatives capable of promoting animal growth without the side effects associated with antibiotics (Placha *et al.*, 2022).

Among these alternatives, probiotics have gained attention because they are composed of live microorganisms that, when administered in adequate amounts, confer health benefits to the host, such as modulation of the gut microbiota and reduction of enteric pathogens (Latif *et al.*, 2023). Yeasts, particularly *Saccharomyces cerevisiae*, are among the most used probiotics and have shown positive

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effects, especially in the ruminal environment. In ruminants, yeasts are used to stabilize pH, increase fiber digestibility, and improve weight gain, in addition to exhibiting immunomodulatory effects in calves and heifers (El Jeni *et al.*, 2024).

Other natural additives have also been investigated as alternatives to antibiotics. Organic acids, for example, reduce the pH of the digestive tract and inhibit pathogen growth. In broiler chickens, the inclusion of these acids has been associated with improved feed conversion and gut health (Kalia *et al.*, 2022). Similarly, phytogenics, composed of essential oils and plant extracts, stand out for their antimicrobial and antioxidant properties, contributing to pathogen control without the use of antibiotics (Ayalew *et al.*, 2022).

In this context of seeking natural and sustainable alternatives, fermented compounds, including kombucha, have gained attention. Kombucha tea is a functional, non-alcoholic or low-alcohol beverage obtained through the fermentation of sweetened green, black, or oolong tea (Camellia sinensis) leaves by **a** symbiotic culture of bacteria and yeasts (SCOBY) using sugar as a substrate (Antolak *et al.*, 2021; Laavanya *et al.*, 2021). Kombucha exhibits many health benefits such as antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and anticancer properties (Laavanya *et al.*, 2021; Kitwetcharoen *et al.*, 2023). This beverage is being explored for its potential to promote gut health, modulate the microbiota, and improve zootechnical performance (Alaei *et al.*, 2020; Ramadhan *et al.*, 2021a; Salehi, Sadeghi & Ahmad Karimi, 2021). Although still scarcely studied in animal nutrition, preliminary research points to promising results, positioning kombucha as a natural and sustainable alternative in animal feeding. Considering the context presented, this review aims to analyze the use of kombucha as an additive in animal feed, focusing on its effects on animal health and performance.

2. METHODOLOGY

This study was conducted as a structured narrative literature review aiming to identify, summarize, and critically discuss the available evidence regarding the use of kombucha as a feed additive in production animals. Although a structured search strategy was employed to identify relevant studies, this review was not designed as a systematic review; therefore, no formal assessment of methodological quality or risk of bias was performed.

The literature search was conducted in ScienceDirect, Web of Science, and PubMed. These databases were selected to ensure comprehensive coverage of peer-reviewed publications in the fields of animal science, veterinary medicine, microbiology, and food science. The search covered studies published between January 2005 and May 2025.

The search strategy was adapted to the syntax and search capabilities of each database. Boolean operators were used to combine keywords related to kombucha and animal nutrition. The search strategy was based on two main concepts: (i) kombucha and (ii) animal nutrition/feed

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supplementation. Synonymous terms within each concept were combined using the Boolean operator OR, whereas the concepts were combined using AND. The search terms included "kombucha", "feed additive", "supplement", "animal nutrition", "poultry", "fish", "swine", "pig", and "ruminant". The search string was adapted according to the requirements of each database while maintaining the same conceptual structure: TITLE-ABS-KEY (kombucha) AND ("feed additive" OR supplement OR animal nutrition) AND (poultry OR fish OR swine OR pig OR ruminant). Studies were considered eligible if they met the following inclusion criteria: (i) original research articles published in peer-reviewed journals; (ii) studies published in English between 2005 and 2025; (iii) investigations evaluating the use of kombucha or kombucha-derived products in production animals; and (iv) studies reporting productive performance, nutrient utilization, intestinal health, immune response, biochemical parameters, product quality, or other health-related outcomes associated with kombucha supplementation.

Studies were excluded if they were review articles, conference abstracts, book chapters, theses, dissertations, duplicate records, studies involving human subjects, experimental studies conducted in laboratory rodents (rats and mice), exclusively *in vitro* studies, publications written in languages other than English, or investigations that did not evaluate the use of kombucha or kombucha-derived products in the nutrition of production animals.

The study selection process was conducted in three stages. First, records identified through the database searches were imported into Zotero reference management software (Corporation for Digital Scholarship, Vienna, VA, USA) for reference management and duplicate detection. Duplicate publications identified by the software were removed before screening. The search initially retrieved 186 records, comprising 150 from ScienceDirect, 7 from Web of Science, and 29 from PubMed. After the removal of duplicate records and the application of preliminary eligibility filters, 175 records remained for screening.

In the second stage, titles and abstracts were evaluated for relevance to the review objective. Studies that clearly did not address kombucha supplementation in production animals, as well as publications that met any exclusion criteria, were removed. This screening process resulted in the selection of 100 records for further evaluation.

In the third stage, full-text versions of the potentially relevant articles were assessed for eligibility. A total of 42 articles underwent full-text review. Articles were excluded at this stage when they did not evaluate kombucha supplementation in production animals, lacked relevant outcome measures, did not provide sufficient experimental information, or failed to meet the predefined inclusion criteria. After the eligibility assessment, 19 studies met all criteria and were included in the final analysis.

Data extraction was performed manually from all eligible studies. The following information was collected from each article: authors, year of publication, country of origin, animal species, experimental design, sample size, kombucha source and preparation method (when available), supplementation level, duration of the experimental period, evaluated variables, and the main findings related to animal

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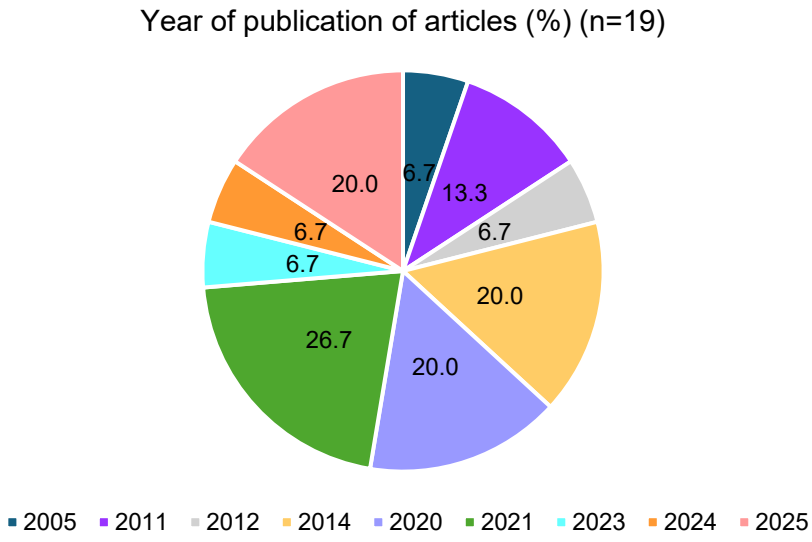
performance, nutrient utilization, intestinal health, immune response, biochemical parameters, and product quality.

The extracted information was organized and synthesized descriptively to identify common findings, research trends, reported benefits, and existing knowledge gaps regarding the use of kombucha in the nutrition of production animals.

3. RESULTS

Figure 1 illustrates the percentage distribution of publication years for the 19 scientific articles that analyzed the use of kombucha in animal feed. 63.15% of the articles were published in the last 5 years, with 2021 being the year with the most publications (26.7%), corresponding to 4 articles. This shows that scientific interest in the use of kombucha as an animal feed additive has increased significantly since 2020. This may be related to the growing search for natural alternatives to antibiotics and the increasing demand for welfare and sustainability in animal production. This trend suggests that the field is growing but is still relatively new and little explored. The total number of articles (n = 19) indicates a gap in scientific literature, which opens space for new original contributions.

Figure 1. Year of publication of articles in percentage about kombucha and animal feed (n=19)



The percentage distribution of scientific articles that investigated the use of kombucha in animal feed is shown in Figure 2. Fish and broilers are the most frequently studied species, together representing almost 60% of the publications. This prominence may be related to the economic relevance and high production potential of these species in agribusiness, which justifies the greater interest in the application of kombucha as an additive or feed supplement in these production systems. On the other

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hand, quails, rabbits, ducks and sheep appear less frequently, being the focus of less than 15% of the articles each, which indicates a low scientific exploration of these species. It is interesting to note that, in general, 36.8% of the studies analyzed are focused on poultry farming, covering broilers, quails and ducks, which shows a growing interest in the application of kombucha in poultry feed. To date, there are no published studies evaluating the use of kombucha in the diets of other ruminant species.

Figure 2. Percentage of articles using kombucha for animal feed according to specie (n=19)

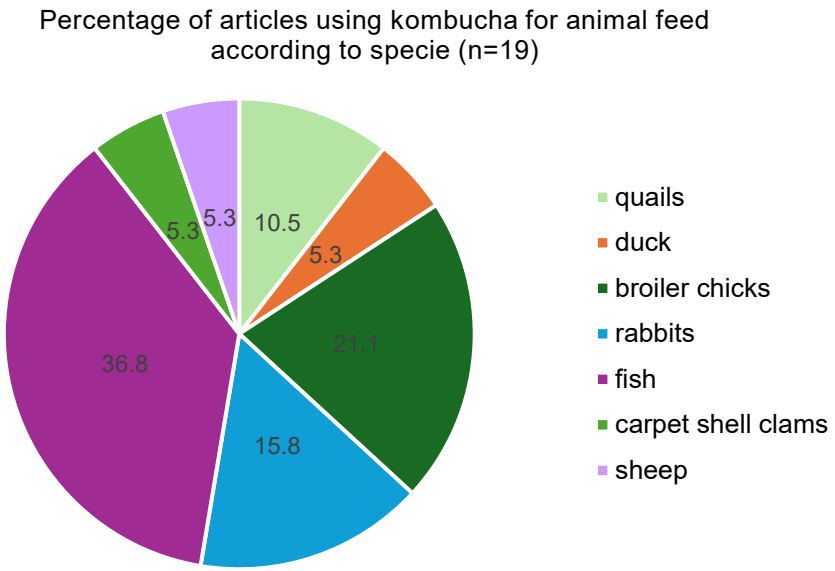

Table 1 shows the 19 articles selected for discussion according to animal species, the objectives of the study, kombucha preparation and fermentation conditions, the treatments used, methods of administration, main results, and references. Based on the analysis of 19 scientific articles, the main research objectives were related to histomorphological measurements (23.10%), blood parameters (20.50%), and performance or growth rate (20.50%). Other studies focused on immune response (17.90%), egg or meat composition and carcass characteristics (12.80%), and intestinal microflora (5.10%). Overall, these findings indicate that most investigations prioritized physiological and productive indicators, while a smaller proportion explored microbial and compositional aspects, reflecting a growing interest in the systemic effects of kombucha on animal health and performance.

Most articles administered kombucha through the diet, with considerable variation in the concentrations used. One article used microbial cellulose film, which is considered a residue of kombucha, in animal feed (Murugesan *et al.*, 2005).

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Table 1. Summary of studies evaluating kombucha supplementation in animal production, highlighting preparation methods, inclusion levels, and main productive and health-related outcomes

Species	Kombucha preparation	Supplementation level	Main findings	Reference
Quails	Tea leaves and sucrose (100 g/L) fermented for 12 days at 25 °C	0, 10, 15, 20, and 25% of diet	Reduced meat fat content without affecting egg fat content.	Adriani *et al.* (2012)
Ducks	Tea leaves and sucrose (100 g/L) fermented for approximately 12 days at 25 °C	10, 15, 20, and 25% of diet	Reduced total cholesterol and LDL levels and increased HDL levels in blood.	Adriani *et al.* (2011)
Broiler chickens	Green tea (amount not reported), sucrose (50 g/L), acidified with vinegar or kombucha starter; fermented at 20–30 °C for 1–8 weeks	Control, probiotic (1 g/kg), kombucha (1.2 g/kg), or green tea powder (10 g/kg)	Increased body weight, feed intake, protein digestibility, villus height, villus height-to-crypt depth ratio, and growth performance.	Afsharmanesh & Sadaghi (2014)
Rabbits	60 g sugar, 30 g black tea, and 100 g SCOBY fermented for 7 days at 27 °C	Standard or high-cholesterol diet with or without kombucha extract (10 mL/kg)	Reduced blood cholesterol and fasting blood glucose levels; increased serum iron and reduced total iron-binding capacity.	Alaei *et al.* (2020)
Broiler chickens	Black tea, 80–100 g/L sugar, and SCOBY fermented for 7 days at 25 °C	5, 10, or 15% kombucha alone or combined with vitamin E + selenium	Increased body weight, improved feed conversion ratio, and enhanced intestinal morphology and lymphoid organ development.	Arani *et al.* (2014)
Fish	50 g/L tea leaves, 150 g/L sugar, and starter culture; fermented for 12 days	4, 6, 8, and 10 mL/kg feed	Increased protein and lipid retention, particularly at 8 mL/kg feed.	Aprianus *et al.* (2021)
Giant gourami	Not described	10, 15, 20, and 25 mL/kg feed	Improved intestinal morphology through increased villus height and enhanced growth performance.	Dila *et al.* (2025)
Rabbits	Black tea (3 g/L), sucrose (200 g/L), and 30 g SCOBY fermented for 2 months at 25 °C	Standard or high-cholesterol diet with or without 5 mL kombucha	No effect on LDL or triglycerides; increased HDL levels.	Pramesti *et al.* (2022)

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Fish	5 g/L tea leaves, 50 g sucrose, and 24 g SCOBY fermented for 14 days at 28 °C	Kombucha diluted 1:2 in water and sprayed onto pellets	Improved weight gain, specific growth rate, and feed conversion efficiency.	Hamdan *et al.* (2021)
Fish	Not described	Diets containing 28 or 29% crude protein, with or without 20 mL kombucha/kg feed	Improved growth rate, protein retention, beneficial intestinal microbiota, and villus length.	Kenconojati *et al.* (2025)
Quails	Not described	0, 10, 15, 20, 25, and 30% of diet	Increased body weight and carcass weight.	Lengkey *et al.* (2012)
Carpet shell clam (*Ruditapes decussatus*)	Red tea (10 g/L), sucrose (100 g/L), 3% SCOBY, and 10% starter culture; fermented for 1 week	Spirulina-based diet with or without 10% freeze-dried kombucha	Improved antioxidant status and resistance against *Vibrio alginolyticus*.	Mansour *et al.* (2025)
Sheep	Not reported	Oral administration of 20 mL kombucha extract for 3 days every 4 months	Improved health status, with absence of parasitic and respiratory disorders compared with controls.	Cortes *et al.* (2014)
Broiler chickens	Kombucha culture maintained in tea medium	0, 50, 100, 150, 200, and 250 g/kg feed	Increased feed intake, body weight, production efficiency factor, and carcass characteristics.	Murugesan *et al.* (2005)
Fish	50 g/L sucrose, 5 g/L tea leaves, 24 g SCOBY, and 0.2 L starter culture; fermented for 10–14 days at 28 °C	Kombucha diluted 1:2 in water and sprayed onto pellets	Improved growth performance, weight gain, specific growth rate, and feed conversion ratio.	Muthusamy *et al.* (2020)
Rabbits	200 g/L sugar, 3 g/L tea, and 100 mL kombucha starter fermented for 9 days	High-cholesterol and lead acetate diet with or without kombucha extract (10 mL/kg)	Prevented the development of atherosclerotic lesions in the aorta.	Rajabzadeh *et al.* (2024)
Fish	50 g/L tea leaves, 150 g/L sugar, and 15 g SCOBY fermented for 12 days	0, 4, 6, 8, and 10 mL/kg feed	Increased weight gain, absolute growth rate, and specific growth rate.	Ramadhan *et al.* (2021)
Siberian sturgeon (*Acipenser baerii*)	Fermented product containing kombucha, milk kefir grains, black tea, sucrose, and bovine colostrum	0, 1, 2, and 3 g/kg feed	Increased meat protein content and reduced fat content.	Rimniceanu *et al.* (2023)

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Broiler chickens	Green tea (1.5 g/L), white sugar or molasses (70 g/L), 10% kombucha starter, and 24 g SCOBY; fermented for 10 days at 25 °C	Drinking water supplemented with 3 or 6 mL kombucha/100 mL water	Increased weight gain, feed intake, protein digestibility, beneficial microbiota, and antioxidant activity.	Salehi *et al.* (2021)

Although most studies reported beneficial effects of kombucha supplementation, direct comparisons among them should be interpreted with caution. Considerable heterogeneity was observed regarding animal species, experimental design, kombucha preparation, fermentation conditions, supplementation levels, administration routes (feed, drinking water or oral extract), and evaluated outcomes. These methodological differences limit direct comparisons across studies and preclude establishing an optimal dosage or a standardized supplementation protocol applicable to different production systems. Therefore, the available evidence should be interpreted as indicative rather than conclusive.

4. DISCUSSION

Kombucha health benefits in human nutrition

Kombucha tea is a functional beverage obtained in the fermentation of sweetened green, black or oolong tea leaves by symbiotic culture of bacteria and yeasts (SCOBY) using sugar as a substrate (Antolak *et al.*, 2021; Laavanya *et al.*, 2021). The therapeutic effect of this beverage in studies using rats or humans, is attributed to the mixture of distinct metabolites such as organic acids, sugars, vitamins, polyphenols, ethanol, amino acids, biogenic amine, hydrolytic enzymes and minerals, fibers formed during the fermentation process (Laavanya *et al.*, 2021; Bishop *et al.*, 2022).

Some of kombucha's metabolites are responsible for human and animal health benefits, with acetic acid being particularly noteworthy. As the predominant organic acid generated during kombucha fermentation, acetic acid is well-recognized for its potent antimicrobial activity. Research indicates that this compound, at a concentration of 5 g/L, exerts a nearly equivalent inhibitory effect on the cell growth and productivity of both Gram-positive and Gram-negative bacteria (Trček *et al.*, 2015). Furthermore, the minimal inhibitory concentration (MIC) for the inhibition of toxigenic and non-toxigenic *Aspergillus flavus* strains was 41.6 mM (2.5 g/L) at pH 4.62 (Peláez *et al.*, 2012). These effective concentrations are notably relevant, as the typical acetic acid level in commercial kombucha beverages varies between 5 and 11 g/L, depending on the specific fermentation parameters employed (Villarreal-Soto *et al.*, 2018). Beyond planktonic inhibition, acetic acid also demonstrated robust antibacterial activity against twenty-nine common wound-infecting pathogens: a concentration of 0.31% successfully prevented biofilm

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formation and achieved complete eradication of mature biofilms across all isolates after just three hours of exposure (Halstead *et al.*, 2015).

Acetic acid also shows clinical potential to lower plasma triacylglycerol and fasting blood glucose (FBG) levels in individuals with type 2 diabetes or overweight. It also helps reduce abdominal fat accumulation and protects against hepatic lipid deposition (Yamashita, 2016; Valdes *et al.*, 2021). Acetic acid and glucuronic acids can conjugate toxins and eliminate them from the body (Ametefe, 2024).

Some organic acids (mainly acetate, butyrate, and propionate) promote the activity of intestinal mucosal immune cells. They activate FFAR2, leading to decreased TNF-α production and increased IL-10 levels. Butyrate also induces the expression of FoxP3, a protein involved in immune system responses, thus increasing the differentiation of extrathymic regulatory T cells (Varela-Mendoza *et al.*, 2025). Acetate is also important for the maintenance of colonocyte homeostasis (Ametefe, 2024).

Glucuronic acid can be converted into glucosamine, a beneficial substance associated with cartilage, collagen, and fluids related to the treatment of osteoarthritis (Nguyen *et al.*, 2015). Furthermore, this organic acid is essential for the body's detoxification process through its role in glucuronidation. Glucuronidation is one of the main hepatic pathways for the biotransformation and excretion of potentially toxic compounds, working by converting liposoluble substances into more polar and water-soluble forms for easy elimination (Adriani *et al.*, 2011; Barroso Filho *et al.*, 2024). Butyric acid and glucuronic acid help to strengthen cell membranes, generally avoiding the infestation by parasites (Cortes *et al.*, 2014). Vitamin C and kombucha contain a high amount of glucuronic acid that can prevent cholesterol accumulation and convert cholesterol to a more water-soluble compound (Rajabzadeh *et al.*, 2024).

Catechin derivatives, originating from tea, are among the key functional compounds in kombucha, representing approximately 30–40% of the dry weight of tea leaves. These molecules exhibit remarkable antioxidant activity—up to 100 times stronger than vitamin C and 25 times stronger than vitamin E, both recognized as potent antioxidants (Adriani *et al.*, 2012). Beyond their antioxidant properties, catechins also display bacteriostatic effects against Streptococcus species and other harmful microorganisms (Mita *et al.*, 2025).

During fermentation, tea polyphenols become more bioaccessible (Liang *et al.*, 2024). This process involves biotransformation of phenolic compounds under acidic conditions and through enzymatic actions of bacteria and yeast within the SCOBY, ultimately influencing the antioxidant potential of the final product (Liang *et al.*, 2024). Taken together, these metabolites present in kombucha contribute to animal health and performance, positioning kombucha as a natural and accessible alternative to improve outcomes in animal production.

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Potential in animal production

The analyzed studies suggest that kombucha holds considerable promise as a natural feed additive, delivering benefits that range from improved zootechnical performance to enhanced intestinal health and favorable biochemical parameters. However, the current evidence remains preliminary and should be interpreted with caution. As summarized in Table 1, the available studies are concentrated mainly in poultry (n = 7) and fish (n = 6), whereas evidence for rabbits (n = 3), sheep (n = 1), bivalves (n = 1), and ruminants (one in vitro study) is still limited. Furthermore, substantial heterogeneity exists regarding kombucha preparation, fermentation conditions, supplementation levels, administration routes (feed, drinking water or oral administration), experimental duration, and evaluated outcomes. These methodological differences hinder direct comparisons among studies and prevent the establishment of standardized supplementation protocols or optimal inclusion levels for different animal **species.**

Growth performance

Growth performance was the most consistently evaluated outcome across the studies. Improvements in body weight gain, growth rate, feed intake and feed efficiency were reported in most poultry and fish experiments (Murugesan *et al.*, 2005; Lengkey *et al.*, 2012; Afsharmanesh & Sadaghi, 2014; Hamdan *et al.*, 2021; Ramadhan *et al.*, 2021; Aprianus *et al.*, 2021; Salehi *et al.*, 2021; Kenconojati *et al.*, 2025; Dila *et al.*, 2025). However, these responses were observed under markedly different experimental conditions, with kombucha concentrations ranging from 1.2 g/kg feed to 30% of the diet, as well as liquid supplementation ranging from 3 mL/100 mL drinking water to 25 mL/kg feed. Therefore, although improvements in productive performance appear to be one of the most reproducible findings, the absence of standardized protocols limits the identification of optimal supplementation strategies.

Gut health and nutrient utilization

Improvements in intestinal morphology, nutrient digestibility and microbial balance were frequently associated with kombucha supplementation, particularly in broilers and fish. Increased villus height, improved villus height-to-crypt depth ratio, greater crude protein digestibility, higher protein retention and increased populations of beneficial intestinal microorganisms were among the most frequently reported responses (Afsharmanesh & Sadaghi, 2014; Aprianus *et al.*, 2021; Salehi *et al.*, 2021; Kenconojati *et al.*, 2025; Dila *et al.*, 2025). Nevertheless, these studies differed substantially regarding kombucha composition, fermentation conditions and administration routes, suggesting that the observed responses are likely influenced by differences in metabolite profiles rather than by kombucha supplementation alone.

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Immune response

Beneficial effects on immune function were reported in relatively few studies and were almost exclusively observed in poultry and aquaculture species. Increased antibody production, greater relative weight of the bursa of Fabricius, enhanced antioxidant enzyme activity (CAT and SOD), and greater resistance against pathogenic microorganisms were reported in broilers and carpet shell clams (Arani *et al.*, 2014; Salehi *et al.*, 2021; Mansour *et al.*, 2025). Although these findings support the hypothesis that kombucha may act as a natural immunomodulator, evidence remains limited and further studies are required to confirm whether these effects are reproducible across livestock species.

Metabolic and biochemical effects

Changes in biochemical blood parameters were mainly reported in rabbits and ducks. Several studies observed reductions in total cholesterol and LDL cholesterol together with increases in HDL concentrations (Adriani *et al.*, 2011; Alaei *et al.*, 2020), whereas another rabbit study reported increased HDL without significant changes in LDL or triglycerides (Pramesti *et al.*, 2022). In quails and sturgeon, kombucha supplementation was also associated with lower fat deposition and higher protein content in meat (Adriani *et al.*, 2012; Rimniceanu *et al.*, 2023). Although these findings suggest favorable metabolic effects, the limited number of studies and the diversity of experimental models prevent definitive conclusions regarding the consistency of these responses.

Overall, the available evidence indicates that the beneficial effects of kombucha are most consistently reported in monogastric species, particularly poultry and fish. Nevertheless, extrapolation of these findings to ruminants should be avoided because digestive physiology, nutrient metabolism, microbial ecology and immune responses differ substantially among animal species. Consequently, positive effects observed in broilers or fish cannot be assumed to occur in ruminants or other livestock species without species-specific validation.

Evidence from ruminants remains particularly scarce. Only one *in vivo* study involving sheep reported improvements in general health status and parasite control (Cortes *et al.*, 2014), whereas a recent in vitro study demonstrated that kombucha-derived microbial metabolites reduced methane production by 15.07% during the first 30 h of ruminal fermentation and by 34.72% during the subsequent incubation period (Kang *et al.*, 2025). Although these findings are encouraging, they should be regarded as preliminary until confirmed under commercial production conditions.

Another important limitation concerns the statistical robustness of the available evidence. Most studies involved relatively small sample sizes, evaluated different response variables, and adopted independent experimental designs. Because of this variability, no quantitative synthesis or meta-analysis could be performed, preventing estimation of pooled effect sizes or assessment of the consistency of responses across studies. Consequently, the conclusions of the present review are

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based on qualitative interpretation of the available evidence rather than on statistically integrated analyses.

Critical appraisal of the available evidence

Even with clear benefits to animal health and production, the literature on the use of kombucha as an additive in animal nutrition remains scarce. Moreover, the current body of evidence is highly heterogeneous, making direct comparisons among studies difficult. The available studies differ considerably in terms of animal species, experimental design, kombucha preparation, fermentation conditions, supplementation levels, administration routes (feed, drinking water or extracts), experimental duration and evaluated outcomes. Consequently, although most studies report beneficial effects, the available evidence should be interpreted with caution, and the current findings should be considered indicative rather than conclusive. Several factors may explain this variability. First, kombucha fermentation depends on the symbiotic interaction between yeasts and bacteria within the SCOBY. The dynamics of this process and its final metabolites are influenced by microbial cooperation and competition, the type of tea or other substrate employed, the initial sugar concentration, and fermentation conditions such as time and temperature (Villarreal-Soto *et al.*, 2018; Landis *et al.*, 2022). As a result, there is batch-to-batch variation. Depending on the fermentation process, microorganisms may follow distinct metabolic pathways, leading to variations in the concentration and profile of metabolites produced, and consequently, in the potential health benefits.

The type of tea used as a substrate significantly affects the resulting bioactive compounds. For instance, kombucha fermented at 25 °C for 15 days using green, oolong or black tea as a substrate showed marked differences. Kombucha prepared from green tea revealed the highest phenolic content and antioxidant activity against DPPH radicals. Conversely, black tea kombucha revealed the highest amounts of organic acids, such as glucuronic acid, gluconic acid, ascorbic acid, acetic acid and succinic acid (Kaewkod *et al.*, 2019). Furthermore, the concentration of polyphenolic compounds in kombucha made from green and white tea was found to increase proportionally with fermentation time (Jakubczyk *et al.*, 2020).

Beyond common tea types, another study showed that while antioxidant activity was higher in black and green kombucha, the rooibos variant demonstrated greater capacity to recover oxidative damage in fibroblast cell lines exposed to oxidative stress (Gaggìa *et al.*, 2019). Similarly, the concentration of essential micronutrients such as manganese, copper, iron, chromium and zinc depended on both fermentation time (1, 7 or 14 days) and tea type (black, red, green or white tea) (Jakubczyk *et al.*, 2022).

Differences in substrate type also directly influence antimicrobial activity. Kombucha produced with green tea inhibited the growth of *Salmonella* spp., *Escherichia coli*, *Staphylococcus aureus* and *Listeria monocytogenes*, with a minimum inhibitory concentration (MIC) of 250 µL/mL. In contrast, black

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tea kombucha showed antibacterial activity only against *S. aureus* and *L. monocytogenes* (MIC = 250 µL/mL) (Cardoso *et al.*, 2020). Antifungal testing further demonstrated that black tea kombucha fermented for 14 days inhibited five resistant *Aspergillus fumigatus* strains, significantly reducing fungal biomass (Nazemi *et al.*, 2019).

Temperature also plays a critical role in metabolite production during fermentation. Ansari *et al.* (2017) reported significantly higher citric acid concentrations in green tea kombucha fermented at 20 °C compared with 30 °C. Likewise, laver kombucha fermented at 30 °C showed higher concentrations of phenolic compounds, whereas fermentation at 25 °C better preserved flavonoids and enhanced anti-diabetic activity through α-amylase inhibition (Aung & Eun, 2022).

Another important limitation concerns the statistical robustness of the available evidence. Most studies evaluated relatively small numbers of animals and reported different response variables, preventing quantitative comparison among experiments. Furthermore, because of the substantial methodological heterogeneity, no meta-analysis or quantitative synthesis has been performed to estimate pooled effect sizes. Therefore, current conclusions rely primarily on qualitative interpretation of independent studies rather than statistically integrated evidence.

Limitations and perspectives

Beyond these biological and technological challenges, additional barriers to the application of kombucha in animal nutrition arise from economic, technical and regulatory constraints. The main economic barriers include production and processing costs, variability and lack of standardization, which increase quality control costs, limited shelf life of liquid products, regulatory requirements for demonstrating efficacy and safety, and competition with cheaper and more established feed additives. From an industrial perspective, large-scale adoption will require standardized production protocols, definition of optimal supplementation levels for different animal species, validation of administration routes (feed, drinking water or extracts), and demonstration of cost-effectiveness under commercial production conditions.

Some metabolites, especially volatile compounds produced during kombucha fermentation, are unstable, and their effectiveness may decrease during feed processing and storage, particularly in raw or unpasteurized kombucha. For example, kombucha stored under refrigeration maintains its polyphenol content and antioxidant activity for approximately four months, after which these beneficial properties gradually decline (La Torre *et al.*, 2021). Future studies should also investigate the stability of bioactive compounds after feed manufacture, pelleting and long-term storage, since these processes may directly affect biological efficacy in animal production.

Although kombucha is generally considered microbiologically safe when produced under controlled conditions, its safety is highly dependent on raw materials, fermentation practices and hygienic conditions. Artisanal production may result in substantial variability in microbial composition,

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allowing the survival or proliferation of opportunistic microorganisms and spoilage contaminants. Cases of contamination with *Aspergillus* and *Penicillium* species have been reported, raising concerns about possible mycotoxin production and associated health risks (Andrade *et al.*, 2025; Ojo & de Smidt, 2023). In addition, excessive consumption has occasionally been associated with metabolic acidosis and gastrointestinal disturbances (Andrade *et al.*, 2025). Potential toxicity may also arise from inadequate production practices rather than from kombucha itself. For example, the use of ceramic vessels coated with lead-containing glazes during fermentation may result in lead leaching into the beverage, posing a risk of heavy metal intoxication. Likewise, poor hygienic practices during fermentation can increase microbial contamination and compromise product safety. Therefore, kombucha intended for use as a feed additive should be produced under standardized hygienic conditions using food-grade containers made of glass, stainless steel or food-grade plastic. These measures are essential to ensure microbiological safety, product consistency and suitability for animal nutrition (Andrade *et al.*, 2025).

Under current regulatory recommendations, there are no specific regulations governing the use of kombucha as a feed additive. However, in the European Union (EU), acetic acid is authorised as both a technological and sensory additive for all animal species. According to the EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP) (2021), maximum concentrations of 2.5 g acetic acid/kg complete feed or 1 g/L drinking water are considered safe for poultry, pigs and companion animals. The establishment of specific regulatory frameworks for kombucha will require standardized production methods, comprehensive safety assessments and consistent evidence of efficacy across different animal species.

Finally, future research should prioritize standardized SCOBY characterization, identification of the metabolites responsible for biological activity through metabolomics approaches, large-scale commercial trials, long-term safety assessments, and evaluation of kombucha's effects on the gut microbiome using omics technologies. Additional studies in ruminants are particularly warranted to confirm its potential role in improving ruminal fermentation, reducing enteric methane emissions and contributing to more sustainable livestock production.

4. FINAL CONSIDERATIONS

This review suggests that kombucha has potential as a natural feed additive and may represent a promising alternative to antibiotic growth promoters in animal production. The available studies generally report positive effects on growth performance, nutrient digestibility, intestinal health, immune response and metabolic parameters, which are likely associated with bioactive compounds generated during fermentation, including organic acids, polyphenols and vitamins. However, these findings should be interpreted with caution, as the current evidence is still limited, heterogeneous and largely restricted to poultry and fish, with relatively few studies involving ruminants and other livestock species.

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Furthermore, differences in kombucha preparation, fermentation conditions, supplementation levels, administration routes and experimental designs hinder direct comparisons among studies and preclude broad generalizations regarding its efficacy.

Future research should prioritize standardized production protocols, characterization of SCOBY composition, optimization of supplementation strategies, and well-designed long-term studies involving different animal species under commercial production conditions. Additional investigations are also needed to evaluate product stability, microbiological safety, regulatory aspects and the mechanisms underlying the observed biological effects.

Overall, the available evidence supports the continued investigation of kombucha as a potential functional feed additive. Nevertheless, further robust and standardized studies are required before its widespread application in animal nutrition can be recommended with confidence.

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