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Review Article

GINGER AS AN ANIMAL FEED ADDITIVE: AN OVERVIEW

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ABSTRACT

Ginger is a natural alternative to antibiotics and is safe for animal and human health. Its use has been reported as an animal feed additive without triggering antibiotic resistance or residues in products. Ginger contains a number of active compounds, *viz.,* terpenes, oleoresin, zingiberol, zingiberone, zingiberene, gingerol, shogaol, zingerone, and paradol, which function as antioxidants, natural antibiotics, and immune stimulants to support animal health and growth. This article employed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) method by identifying articles from various scientific report source databases, *viz.,* PubMed, Scopus, Science Direct, and Elsevier. The articles and reports (n=130) were selected between the years 2014 to 2021. The literature survey findings revealed that ginger is a natural alternative to antibiotics that can increase the growth and productive efficiency of poultry, ruminant, and aquaculture. The use of ginger as a feed additive can support organic farming activities to protect the environment, humans, and animals, thereby potentially increasing the sustainability of the animal production sector.

Keywords: Aquaculture, ginger, phytogenic feed additives (PFA), poultry, ruminants, *Zingiber officinale* Roscoe.

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INTRODUCTION

The demand for animal protein products has increased globally over the past many years (Abou-Kassem *et al.*, 2022). The intensive global expansion of animal agriculture demands has increased the use of antibiotics to treat and prevent infections and to promote growth when added to the diet at sub-therapeutic levels (Nhung *et al.*, 2017). The global demand for antibiotics increases every year. Tiseo et al (2020) reported 11.5% rise in global sales of antibiotics in 2030 compared to 2017. The global sales of antibiotics for chickens, cattle, and pigs in 41 countries in 2030 are estimated to be 104,079 tonnes China is usually considered as the largest antibiotic-consuming country in the world. Based on livestock intensification patterns and aquaculture trends, Indonesia is projected to experience an increase in antibiotic consumption. The excessive use of antibiotics as a feed additive in animal feed has gradually led to antibiotic resistance in pathogenic microbes (Giannenas *et al.*, 2019). The World Health Organization (WHO) defines antibiotic or antimicrobial resistance (AMR) as "a state in which bacteria, viruses, fungi, and parasites change over time and no longer respond to drugs, making infections more difficult to treat and increasing the risk of disease spread, severe illness, and death." The effect of AMR and residues in farm animals has changed consumer perceptions of animal protein products *viz.,* meat, milk, and eggs. The North American government has taken steps by enacting more stringent regulations against beef producers raising beef cattle without antibiotics and ionophores (Lekagul *et al.*, 2019). The National Organic Program has also taken steps to reduce the use of antibiotics, hormones, herbicides, and pesticides to protect the environment, humans, and animals, and to support organic farming and sustainable agricultural efforts (Zhang *et al.*, 2021).

Medicinal plants are an alternative to natural antibiotics (Arif *et al.*, 2022) that can support animal growth and health (Brum *et al.*, 2018b). Phytogenic substances contained in medicinal plants are safe materials for use in animal nutrition and have several other advantages over synthetic antibiotics (A Al-Sagan *et al.*, 2020). The beneficial role of medicinal plants in livestock nutrition includes but is not limited to as a source of minerals and vitamins, livestock's appetite stimulation, improvement in digestive efficiency of ruminants (Fahim *et al.*, 2022) complementing the performance of other feed additives and growth promoters like ionophores (Khattab *et al.*, 2020), acting as an immune stimulant (Elwan *et al.*, 2020) and having antimicrobial, antiparasitic, antiviral, and antioxidant

activities to make livestock healthy and productive (Giannenas *et al.*, 2019). In addition, medicinal plants may increase the activity of lymphocytes, macrophages, and natural killer cells, support phagocytosis, and stimulate interferon synthesis (Dawood *et al.*, 2021). One of the medicinal plants that can be used as an alternative to natural antibiotics is ginger (*Zingiber officinale* Roscoe) (Abd El Tawab *et al.*, 2020).

Ginger is a medicinal plant (rhizome) that has many benefits in livestock production. It contains derivative functional essential oils (zingiberene, curcumin, geraniol, citronyl acetate, terpineol, linalool, borneol, neral, and geranial), phenols, and flavonoids (Srinivasan, 2017). Ginger also contains organic acids (malice, citric acid, and tartaric acid), being useful as an antiviral, anti-inflammatory, anti-stomach, antioxidant, antibacterial, antidiarrheal, antispasmodic, astringent, hepatoprotective, antiulcer, fungicide, cyclooxygenase inhibitor (Kate and Sutar, 2020) and lipoxygenase inhibitors. These activities relate to the presence of flavones and phenolic acids, such as gallic acid, myricetin, quercetin, isoquercitrin, and tannic acid (Morvaridzadeh *et al.*, 2020) in ginger. The dry powder of the ginger rhizome is reported to contain 60–70% carbohydrates, 9% protein, 3–6% lipids (glycerides, lecithin, and fatty acids), 3–8% fiber, 2–6% proteases, 1–3% volatile compounds (gingerol, shogoal, zingiberol, zingiberene, terpenes, oleoresin, zingiberen, and zingerone), and vitamins A, C, and B_3 (Hsiang *et al.*, 2013). Gingerol plays a role in the production of the pungent smell and taste of ginger, which increases the food's palatability and stimulates the secretion of digestive enzymes (Ahmadifar *et al.*, 2019). Terpenes, oleoresin, zingiberol, zingiberon, zingiberene, gingerol, shogaol, zingerone, and paradol presence in ginger resulted in immune-stimulating (Si *et al.*, 2018), antibacterial (Beristain-Bauza *et al.*, 2019), and antiparasitic effects (Fu *et al.*, 2019).

Restrictions and in some countries complete ban on the use of synthetic antibiotics have increased the use of medicinal plants, especially ginger, as feed additives in livestock, poultry, and aqua production (Helal *et al.*, 2019). Ginger, as a nutraceutical, may provide all the important elements necessary to support animal health and productivity (Yadav and Jha, 2019). This is mainly achieved by increasing the bioavailability and efficiency of feed utilization for better yields (Junaid *et al.*, 2018). The use of ginger is considered safe for consumption by humans and animals and is categorized as Generally Recognised as Safe (GRAS) in European Union (EU) countries under the European Food Safety Authority (EFSA) and in the United States (US) by the Food and Drug Association (FDA) (Ali *et al.*, 2008; Hsiang *et al.*, 2013; Mao *et al.*, 2019) Animal nutritionists and veterinarians are reportedly exploring secondary metabolites from various medicinal plants, including ginger, which have antibiotic properties against various microorganisms, thereby increasing the efficiency of animal production, especially poultry, pig, ruminant, and aquaculture(Yadav and Jha, 2019).

This article specifically examines the use of ginger as an alternative to natural antibiotics. The focus of this article is to review several important aspects of using ginger as a feed additive, with particular reference to ruminants, poultry, and aquaculture production. The information in this article is expected to be a reference for the future animal industry oriented toward health and consumer demands.

MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) guidelines were used in this review. This was achieved through the first step of identifying articles in various sources of scientific reports, including PubMed, Scopus, Science Direct, and Elsevier, using the keyword "ginger" combined with Zingiber officinale Roscoe, phytogenic feed additive (PFA), ruminants, poultry, and aquaculture. At the identification stage, the articles were chosen from the year 2014 to 2021. During the second step, the articles were selected by reviewing the relevance of the title of the articles obtained with the sub-topic of the research discussion. The search results of the selected article database, which included 130 out of 500 articles and reports, were included in the criteria. The third step was validation, which was achieved by reviewing the depth and quality of the content of the articles and their relevance to the sub-topic of the research discussion. The fourth step was the article review. The various steps are represented in Figure 1.

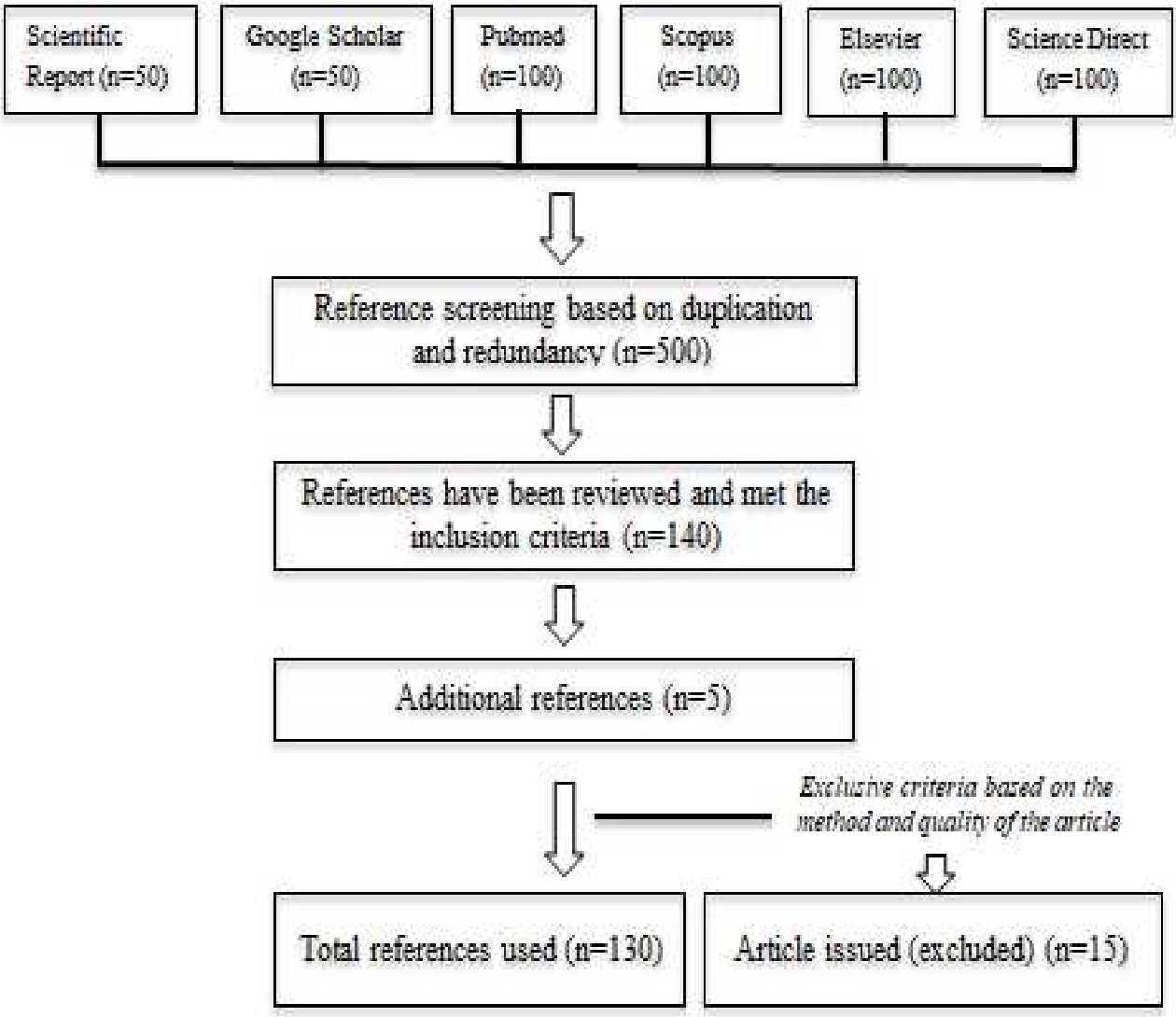

Figure 1. Flow chart for the identification of studies by databases and records (Adapted from (Pahlevan *et al.*, 2019) **; and** (Page *et al.*, 2021)**).**

RESULTS AND DISCUSSION

Ginger as a feed additive: According to the WHO (2018), one of the major problems faced due to the intensive use of antibiotics is the occurrence of microbial resistance to infectious diseases, such as pneumonia and salmonellosis. Restrictions on the use of antibiotics, as feed additives, to suppress the spread of these negative effects have been reported in various countries including Korea, Vietnam, China, Australia, and Latin America (Suresh *et al.*, 2018). Restrictions on the use of antibiotics as feed additives have led to an increase in the use of botanical ingredients as natural alternatives to improve animal health, growth rate, productivity, and animal fitness (Stevanović *et al.*, 2018). Antibiotic-free animal products are a major target in the animal industry. Efforts to produce antibiotic-free animal products also require new approaches to animal feeding, management, and breeding, especially in maintaining animal growth (Reda *et al.*, 2020). Different feed additives, including biologically synthesized nanoparticles, probiotics, prebiotics, synbiotics, medicinal plant extracts, essential oils, organic acids, enzymes, and essential amino acids, have been widely used to replace the use of antibiotics in feed (El-Saadony *et al.*, 2021a; 2021b; 2021c; 2022). Ginger is a medicinal plant that can be used as an alternative to natural antibiotics (Abd El Tawab *et al.*, 2020).

Ginger contains a number of nutraceutical compounds that have pharmacological impacts on the animal body owing to its therapeutic activities, including antimicrobial, anti-inflammatory, antioxidant, sedative, adaptogenic, immunomodulatory, and free radical scavenger effects (Mao *et al.*, 2019; Garza-Cadena *et al.*,

2023). Nutraceuticals are reported to be derived from probiotic organisms and nutraceutical enzymes (primary or secondary metabolites), as well as constituent chemicals, such as nutrients, phytochemicals, and medicinal plants (Attiq *et al.*, 2018). Natural active compounds (phytobiotics) produced by ginger can be used as phytogenic feed additives (PFA) to improve animal health and growth (Tiwari *et al.*, 2018). Phytogenic feed additives are a promising alternative to synthetic feed additives. The phytogenic class contains four main subgroups, *viz.,* herbs, plants, essential oils, and oleoresins (Abdelnour *et al.*, 2020a; 2020b). Phytogenic feed additives are used by nearly 80 countries in the EU. The increase in the use of PFA during the animal husbandry period is not only based on animal and human health concerns as consumers but also an effort towards sustainable agriculture through increasing the widespread use of nature-based and environmentally friendly products (Mountzouris *et al.*, 2011). Ginger has long been used in animal health management, especially in ethno-veterinary practices. The use of ginger as a natural alternative to synthetic feed additives has been developed as a future effort for the animal industry oriented to fulfill consumer demands for safer animal products. Ginger is used as a sensory additive for feed conversion, improving meat quality and prophylactic purposes, and as a substitute additive for growth-supporting antibiotics (Vyas *et al.*, 2018). Ginger supports efficient follicular development and immunity, thereby increasing production yields. It has a positive effect on gastric secretions, thereby increasing feed consumption and production by increasing the activity of digestive enzymes (Wang *et al.*, 2020). Optimal gut function, increase nutrient absorption, animal health, and fitness can be met when animals have healthy gut microbiota, balanced dietary factors, intestinal mucosa, and immune responses to suppress pathogens, and modulate inflammation (Ogbuewu and Mbajiorgu, 2020).

Ginger can support animal growth due to its antibacterial activity that suppresses the influence of pathogenic microbiota in the intestines, thus improving digestion, and (Kairalla *et al.*, 2022). Ginger contains gingerol, gingerdiol, and ginerdione, which increases the activation of digestive enzymes, causing high feed utilization (Abou-Kassem *et al.*, 2022) thus improving the growth performance, immunity, and antioxidant capacity of animals (Ogbuewu *et al.*, 2020). The rhizome has antibacterial activity to reduce the impact of pathogenic bacteria (mesophilic aerobic, coliform, and *Escherichia coli*) on digestive capacity, and increases the activity of beneficial bacteria (lactic acid bacteria), thus enhancing secretion of digestive enzymes and efficient nutrient digestion and absorption (Kairalla *et al.*, 2022). Ginger has antioxidant activity (Yatao *et al.*, 2018). that can increase animal resistance to stress conditions (Jalali *et al.*, 2020). It has anti-inflammatory and wound-healing properties due to its abundant tannin content and flavonoid derivatives that protect against allergies, platelet aggregation, and microbial infection (Morvaridzadeh *et al.*, 2020). It has been reported to increase nutrient absorption by stimulating lactic acid bacteria and reducing the number of pathogenic bacteria (Reda *et al.*, 2021a). Ginger is also reported to have anti-hypercholesterolemic activity, which plays a role in reducing stress conditions and increasing serum total protein levels to increase the synthesis and transport of sex hormones (Xie *et al.*, 2017).

Furthermore, the addition of 50 or 100 g of ginger/head/day to Holstein cattle diets significantly increased milk production compared to basal rations Vyas et al, (2018) reported that. Supplementation of 75 or 150 g of ginger root powder/cow/day significantly increased feed intake, milk production, fat, protein, lactose, % milk lactose, red and white blood cell count, the concentration of hemoglobin, packed cell volume, % of lymphocytes, total protein, and globulins (Al-dain and Jarjeis, 2015). The use of ginger as a feed additive for animal health and growth has also been widely reported, including supporting the health and growth of ruminants, poultry, and aquaculture (Tiwari *et al.*, 2018).

Effect of ginger as a ruminant feed additive: Natural active compounds (phytobiotics) produced by ginger can be used as phytogenic feed additives (PFA) to improve ruminant's health and growth. Phytobiotics and phytochemicals have advantages, such as being easily found, having low production costs, and being able to suppress the occurrence of antibiotic resistance (Tiwari *et al.*, 2018). Stimulation of feed intake from plants, especially ginger, has been reported to increase the diet palatability, nutrient digestibility, growth rate, and feed conversion ratio (Yadav *et al.*, 2016). Better growth of intestinal microflora, antimicrobial potential, coccidiostats, immunostimulation, and anthelmintic effects of ginger feeding has also been reported that have eventually increased the safety, health, and ruminant meat quality (Yadav *et al.*, 2016). This, in turn, increases the quality of animal products and storage time (Gheisar *et al.*, 2018). Ginger can increase saliva secretion, which causes increased secretion and activity of digestive enzymes, ultimately improving the digestive process. The rhizome helps increase the absorption of essential nutrients to promote animal growth, accelerate the digestive process, and slow down the feed passage rate through the digestive tract (Vyas *et al.*, 2018). They further reported improved feed stability and gastrointestinal ecosystem by inhibiting the growth of pathogenic microorganisms (Vyas *et al.*, 2018).

Table 1. Potential of ginger as a feed additive in ruminants.

No	Secondary Metabolites	Benefit		Chemical Process	Impact
		Category	Type		
1.	Dehydrogingerdione	Health	Digestion	Urine excretion	Protection of the liver and kidneys
2.	Saponin	Health	Digestion	Increased the number of beneficial protozoa and the fermentation process, reduced the number of unfavourable protozoa in the rumen digestive system, and facilitated the process of feed organic matter degradation.	Increased total volatile fatty acid (VFA) values, the concentration of acetate, propionate, butyrate, NH_3, and CH_4 in the rumen (Mardalena, 2015; Hapsari *et al.*, 2018).
3.	Essential oil	Health	Digestion	Stimulated the central nervous system for appetite regulation, stimulated digestive juice to produce a pH that matches digestive enzymes, increased saliva secretion, increased appetite, facilitated feed absorption in the small intestine, antibacterial activity, antifungal, increased digestive enzyme activity, optimised the performance of bacteria in the rumen, improved digestive processes, as well as nutrient absorption, and increased the number of cellulolytic bacteria.	Increased body weight of crossbreed cattle, decreased occurrence of diarrhoea and other digestive diseases, maximum absorption of feed, optimal daily growth, drier and odourless manure with reduced fly population in the pen , increased secretion and activity of digestive enzymes (Wurlina *et al.*, 2018; Ebeid *et al.*, 2020a; Kholif *et al.*, 2021a; Fahim *et al.*, 2022).
		Ruminant Production	Milk production	Increased ruminal acetate, increased stability of the gastrointestinal ecosystem, stimulated the endocrine system, activated the immune system, increased the milk fat concentration, and inhibited the growth of pathogenic microorganisms.	Increased milk production and content of non-fat milk solids, protein and lactose (Kholif *et al.*, 2018; 2019; 2021b; Al-Musodi and Jaafar, 2019; Mahmoud *et al.*, 2020; Fahim *et al.*, 2022).
		Ruminant Production	Meat production	Increased milk production and content of non-fat milk solids, protein and lactose.	Increased meat production (Al-Musodi and Jaafar, 2019).
		Health	Immune	Increased feed utilisation and nutrient absorption, activated the immune system, and stimulated the endocrine system.	Improved ruminant body fitness (Kholif *et al.*, 2021b).
4.	Camphene, neral, -bisabolene, ar-curcumene, -eudesmol	Health	Digestion	Antimicrobial activity by suppressing unfavourable microbes.	Reduced development of protozoa in the rumen without interfering with ruminal cellulolytic activity (Ebeid *et al.*, 2020b).

Ginger increases the feed fermentation ability of the rumen. The administration of 0.005 ml of ginger extract in dairy cattle feed has a significant effect on increasing the total VFA and concentrations of acetate, propionate, butyrate, NH_3, and CH_4 in the rumen (Hapsari *et al.*, 2018). This increase is due to the presence of active compounds in ginger in the form of saponins, which are thought to reduce the number of unfavorable protozoa, thereby increasing the number of beneficial bacteria. Increasing the number of bacteria in the rumen will increase the fermentation process and facilitate the degradation of organic matter in the feed so that the total VFA value increases. The high concentration of total VFA indicates the amount of organic matter in the diet that is easily degraded by rumen microbes (Mardalena, 2015). The addition of ginger as a growth promoter increases the body weight of Simmental and Limousine crossbreed cattle. Ginger contains essential oils that can increase appetite and facilitate the absorption of nutrients in the small intestine. The smell and taste of ginger essential oil can stimulate the central nervous system to increase the appetite and stimulate digestive juices to maintain a pH that is followed by digestive enzymes, such as peptidase, thus reducing the occurrence of diarrhea and other digestive diseases observed in ruminants (Wurlina *et al.*, 2018). In the digestive tract, there are many bacteria, protozoa, worms, and fungi. The administration of ginger as a growth promoter having antibacterial and antifungal activities increases the activity of digestive enzymes thus improving nutrient absorption and metabolism, weight gain was noted in cattle (Ebeid *et al.*, 2020a). The administration of ginger has also been reported to optimize the ruminal bacterial working in the rumen that resulted in optimal feed fermentation, nutrient absorption, daily growth, and, drier and odorless feces, with a reduction in fly population in the cages (Wurlina *et al.*, 2018). In addition to cows, ginger (75 g of ginger/per buffalo/day) also improves the digestive process, nutrient absorption, and milk production in buffaloes (Fahim *et al.*, 2022).

The administration of ginger is reported to have a positive impact on goat meat production. The addition of 2 ml of ginger oil/head/day to the diets of Damascus goats significantly increases the dry matter intake compared to the basal ration. Ginger contains essential oils that can affect rumen fermentation and feed digestion. Moreover, that giving ginger supplements @ 60 g/kg of diet concentrate to Iraqi goats increased the milk yield and milk content of non-fat solids, protein, and lactose (Souza *et al.*, 2019b). Ginger supplements increase saliva secretion, which results in increased secretion and activity of digestive enzymes, thereby improving the digestive process by increasing the number of cellulolytic bacteria (Ebeid *et al.*, 2020b). The rhizome is reported to contain camphene, neral, β-bisabolene, ar-curcumin, β-eudesmol, and other compounds that are antimicrobial and suppress the development of protozoa in the rumen without interfering with ruminal cellulolytic activity (Ebeid *et al.*, 2020a). The use of ginger with other medicinal plant ingredients has been reported to increase the effectiveness of ginger utilization. Kholif *et al* (2021a) reported that ginger used with fennel improved the digestive system of animals and increased milk production by 10.5% and 11.6%, respectively. A similar observation was reported by (Al-Musodi and Jaafar, 2019) and (Kholif *et al.*, 2018; 2019) on Iraqi goats that were breastfed and given ginger supplementation for 5 months. The goats were reported to have an increased concentration of milk fat of up to 17.9% due to increased ruminal acetate. Ginger and fennel increase the absorption of important nutrients, which causes increased milk production (Mahmoud *et al.*, 2020). The rhizome improves the stability of the gastrointestinal ecosystem by inhibiting the growth of pathogenic microorganisms, resulting in better milk production. Phytogenic supplementation increases feed utilization and nutrient absorption, activates the immune system, and stimulates the endocrine system (Kholif *et al.*, 2021b).

Effects of ginger as a poultry additive: Phytogenic feed additives are compounds derived from plants, like essential oils, spices, safe natural compounds, and herbs. The phytogenic properties of PFAs depend on their chemical composition, degree of dietary inclusion, bird genetics, and feed composition (Ferdous *et al.*, 2019). The ban on the use of antibiotics as growth promoters in dietary feeds has increased the use of natural feed additives. Ginger contains PFA that can provide health benefits when added to poultry feed (Beristain-Bauza *et al.*, 2019; Abo-EL-Sooud, 2018). Ginger as a phytobiotics can also improve the feed taste, increase feed consumption, and stimulate the secretion of digestive enzymes and antimicrobial activity, thus causing improved poultry growth and antimicrobial activity against pathogenic bacteria (Abo-EL-Sooud, 2018; Dawood *et al.*, 2021).

Ginger as a nutraceutical ingredient suppresses the growth of harmful organisms through mucus secretion from the intestinal epithelial tissues., This causes low pathogenic adhesion and enables beneficial microorganisms to enhance gut immunity. The rhizome has active derivatives that are involved in stimulating the digestion and absorption of nutrients through the intestinal villi, thereby increasing nutrient digestibility in poultry (Sa'aci *et al.*, 2018). High feed utilization is associated with an increase in villi length, which causes an increase in the area for nutrient absorption (Dawood and Koshio, 2020). Ginger is reported to have pharmacological effects that reduce the impact of stress on poultry, including antiapoptotic, immunomodulatory, antitumorigenic, antiapoptotic, anti-inflammatory, antihyperglycemic, antiapoptotic, antilipidemic, and

Table 2: Potential of ginger as a feed additive in poultry.

No	Secondary Metabolite	Benefit		Chemical Process	Impact
		Category	Type		
1.	Essential oil	Health	Digestion	Antimicrobial, Antiviral, antioxidant, and antiparasitic activity, improved metabolic function, inhibited cellular cholesterol biosynthesis, and improved absorption and digestion processes.	Increased activity of digestive enzymes, decreased number of pathogens, increased digestive nutrients, increased accessibility of essential nutrients to the gut, increased antioxidant capacity and immune function in broilers, and suppressed cholesterol levels (Abo-EL-Sooud, 2018).
2.	Polyphenol, Flavonoid, Shogaol, Gingerol,	Health	Antioxidant	Counteracted free radicals, inhibited lipid peroxidation, increased antioxidant capacity, and enhanced immune function.	Increased poultry immunity (Abo-EL-Sooud, 2018; Noura and Heshmat, 2019).
	Monoterpene derivatives, and	Health	Antibiotics	Improved haematology, biochemistry, and growth of broilers.	Improved health and blood parameters in broilers (Gilani *et al.*, 2018; Kholif *et al.*, 2021b).
	Sesquiterpene	Poultry Production	Egg Production	Increased egg production, egg weight, and egg mass, reduced cholesterol levels in eggs, increased feed intake and production rate, increased glucose level, reduced triglycerides and serum cholesterol, and increased mushroom catalase (CAT), nitric oxide (NO), glutathione peroxidase (GSHPX), and total protein levels (T-AOC).	Increased the quality and quantity of chicken eggs (Gurbuz and Salih, 2018; Nawab *et al.*, 2018; Ibtisham *et al.*, 2019).
		Health	Fitness	Increased palatability, enzyme function, and mucus production in the intestine.	Increased antimicrobial activity, increased immunity, and increased digestive system function (El-Saadony *et al.*, 2022).
3.	Isoprene derivatives, Flavonoid, Glucosinolates	Health	Poultry physiology	Stabilised the role of the gut microbiome in the process of nutrient metabolism.	Improved physiological function and chemical function in the avian intestine (Reda *et al.*, 2021b; Saad *et al.*, 2021a; 2021b; 2021c).

antiemetic effects. It can also improve digestive function by stimulating the secretion of gastrointestinal fluids and increasing lipase and maltase activities. The compounds contained in ginger can bind to serotonin receptors that affect gastrointestinal function and stimulate synthetic growth (Ibtisham *et al.*, 2018). Alagawany *et al* (2021) reported that ginger essential oil has antimicrobial, antiviral, antioxidant, and antiparasitic properties that can increase digestive enzyme activities, accessibility of essential nutrients in the intestine, and reduce the number of fermented products and pathogens. In addition, ginger can increase antioxidant capacity and immune function in broilers. Abdel-Gabbar *et al.* (2019) reported lower cholesterol levels in ginger-fed broilers owing to the release of ginger secondary metabolites that can improve the metabolic function, and inhibit cellular cholesterol biosynthesis, with an increase in nutrient digestion and absorption, antioxidant effects, and antimicrobial activity. The potential role of polyphenols and flavonoids in ginger is also involved in scavenging free radicals and inhibiting lipid peroxidation. Ginger contains shogaol, gingerol, monoterpene derivatives, and sesquiterpenes that function as natural antioxidants (Noura and Heshmat 2019).

In addition to the use of ginger alone, its use in combination with other medicinal plant ingredients has been reported to increase the effectiveness of its use as a PFA (Kholif *et al.*, 2021b). Gilani *et al.* (2018) reported that a phytobiotic combination of ginger and *Glycyrrhiza glabra, Withania somnifera, Camellia sinensis, Nigella sativa,* and organic acids improved health and blood parameters in broilers. The combination of ginger phytobiotics and organic acids can also be used as an alternative to antibiotics. Karangiya et al (2016) used a mixture of garlic, ginger, and chaya leaves that improved the performance of hematological and biochemical processes, as well as growth in broilers. In addition to broilers, ginger supplementation in the diet of laying hens has also been reported to increase egg production, weight, and mass (Gurbuz and Salih, 2018). Ginger extract (0.1%) given to laying hens increased the antioxidant capacity and immune function in chickensGinger also has the potential of reducing the inflammatory response in chickens (An *et al.*, 2019). Ginger supplementation @0.50 or 0.75% increased egg production and reduced cholesterol levels in eggs (Ibtisham *et al.*, 2019). Supplementation of 10 g ginger powder per kg of diet increased the feed intake, production rate, glucose, mushroom catalase (CAT), nitric oxide (NO), glutathione peroxidase (GSHPX), and total protein levels (T-AOC) with reduced serum triglycerides and cholesterol levels (Nawab *et al.*, 2018). In addition to these, ginger supplementation is also reported to increase the health and fitness of birds. Abd El Hack *et al.* (Abd El-Hack *et al.*, 2021; 2022) reported that ginger improved the fitness and health of birds through antimicrobial and antioxidant activities, as well as boosting immunity, and improving the digestive system. Ginger improves gut health by increasing palatability and digestive function by increasing enzyme function and mucus production in the intestine (El-Saadony *et al.*, 2022; El-Saadony *et al.*, 2021d). Isoprene derivatives (Reda *et al.*, 2021b), flavonoids (Saad *et al.*, 2021b), glucosinolates, and other herbal metabolites from ginger can affect the physiological and chemical functions in the bird's gut by stabilizing the role of the gut microbiome during the process of nutrient metabolism (Saad *et al.*, 2021a; 2021c).

Effects of ginger as a fish feed additive: Nutrition is an important parameter in increasing fish production (Aqmasjed *et al.*, 2023). The nutritional status of fish plays an important role in increasing the immunity and fitness of fish (Souza *et al.*, 2019a). Natural additives from medicinal plants, especially ginger, have been used in fish farming to improve fitness, feed efficiency (Chung *et al.*, 2020), digestion, and nutrient absorption (Souza *et al.*, 2019b). Ginger types (plant extract or dry powder), varieties used, agronomic practices, and drying and storage conditions resulted in variations in ginger composition that have different effects on fish performance (Ahmadifar *et al.*, 2019). Ginger provides benefits for fish health through antimicrobial (Souza *et al.*, 2019b; Dawood *et al.*, 2021), antioxidants, and immune stimulants activities (Souza *et al.*, 2019a). Ginger acts as a digestive stimulant and is effective in increasing protein and lipid metabolism and fish growth rate (Mohammadi *et al.*, 2020). Several studies have demonstrated the effects of ginger or its compounds on fitness, antioxidant status, immune system, and serum metabolites in fish species (Singha *et al.*, 2020). Gingerol also acts as a hepatoprotective and immune modulator (Mao *et al.*, 2019) and prevents hyperglycemia, hyperlipidemia, and functional digestive disorders (Shang *et al.*, 2019). (The use of ginger as a food additive provides benefits for growth, digestibility (Souza *et al.*, 2019a), and nutrient absorption of fish (Souza *et al.*, 2019b). Detailed data on ginger as a feed additive in fish production is presented in Table 3.

Platelets in fish play a role in the coagulation process and help in defense mechanisms. Plasma albumin levels are also an indicator of immune status in fish (Hoseini and Yousefi, 2019). Increased levels of hemoglobin can promote a greater supply of oxygen to the physiological system. Ginger can increase blood glucose levels, resulting in increased catecholamine secretion, thereby increasing insulin resistance (Walker *et al.*, 2020). The rhizome is rich in polyphenolic compounds that protect against the damaging effects of oxidative stress and inflammation through the inhibition of enzymatic and signaling systems involved in

Table 3: Potential of ginger as a feed additive in fish farming.

No	Secondary Metabolites	Benefit		Chemical Process	Impact
		Category	Type		
1.	Polyphenol compounds	Health	Immunity	Increased blood glucose levels, increased catecholamine secretion, inhibited enzymatic and signalling systems in inflammatory processes, regulated nitric oxide production.	Increased resistance to insulin and protected against damage from oxidative stress and inflammation (Hoseini and Yousefi, 2019; El Asely *et al.*, 2020; Walker *et al.*, 2020).
2.	Essential oil	Health	Fitness	Promoted growth, enhanced immune response, improved juvenile metabolism, had antioxidant properties, increased intestinal villi size and haematological variables, increased plasma cholesterol levels, increased leukocyte values and haematological variables, improved the physiological status and intestinal morphology, improved digestive tract morphology, and increased mucosal integrity.	Immunostimulants, antioxidants, and increased fish growth parameters and fish weight gain (Brum *et al.*, 2017; Valladão *et al.*, 2017; Brum *et al.*, 2018a; 2018b; Owatari *et al.*, 2018; Hoseinifar *et al.*, 2020; Singha *et al.*, 2020; Chung *et al.*, 2021a)
		Health	Haematology	Increased the haematological variables of fish, prevented liver pathology and fat accumulation, and increased the digestibility of complex nutrients.	Increased the fitness and utilisation of nutrients in fish and increased the activity of digestive enzymes (Jahanjoo et al, 2018; Mohammadi *et al.*, 2020; Singha *et al.*, 2020).
3	Zingiberene, sesquiphellandrene, arcurcumene	Health	Fitness	Inhibited the action of free radicals and lipid peroxidation, increased the number of leukocytes, haemoglobin, and platelets, and stimulated the formation of leukocytes.	Improved physiological function and health of fish, increased immunological defence of fish, increased non-specific immunity, and reduced inflammatory cell production (Mohammadi *et al.*, 2020; Nyadjeu et al, 2020; Chung *et al.*, 2021a; 2012b).
4.	Phenol, flavonoid	Health	Antioxidant	Increased immunoglobulins, alternative complement activity, lysozyme activity, amylase activity, immunological responses, defence gene expression, erythrocytes, haemoglobin, and haematocrit.	Increased antioxidant activity and fish immune system, increase oxygen transport to body tissues (Ahmadifar *et al.*, 2019; Copatti *et al.*, 2019; Mohammadi *et al.*, 2020).
5.	Zingerone	Health	Fitness	Affected the spleen and thymus, stimulated leukocyte secretion, increased the Ig content of fish serum, activated immune cells, and had antioxidant, antibacterial, antiparasitic, and anti-inflammatory activity.	Increased the number of leukocytes (Hoseini and Yousefi, 2018; Hajirezaee et al, 2020).
6.	Terpen, oleoresin, zingiberol, zingiberon, zingiberen, gingerol, shogaol, zingeron, and paradol	Health	Fitness	Increased the Ig content of fish serum, activated immune cells, had antioxidant, antibacterial, antiparasitic, and anti-inflammatory activity.	Increased immunity to danger and stress (Si *et al.*, 2018; Ahmadifar *et al.*, 2019; Fu *et al.*, 2019; Fazelan *et al.*, 2020)
7	6-gingerol, 8-gingerol, dan 6-shogaol	Health	Antibacterial	Inhibited the formation of biofilm *Vibrio parahaemolyticus* bacteria causing necrosis.	Protected shrimp from necrosis diseases (Yatip *et al.*, 2018; Soowannayan *et al.*, 2019a; 2019b).
8	Gingerol dan diarylheptanoids	Health	Antioxidant	Protected fish against insecticide chemical toxicity and bisphenol A (BPA)-induced interference, and addressed biochemical changes, chromosomal aberrations, and pathological changes induced by exposure to insecticides.	Increased antioxidant capacity in fish (Mohammed *et al.*, 2020; Soror *et al.*, 2021).

inflammatory processes that regulate nitric oxide production (El Asely *et al.*, 2020).

Brum *et al.* (2018a) reported that ginger essential oil in tilapia feed increases the growth, immune response, and metabolism of juvenile fish. Supplementation with 1.0 and 1.5% ginger increases the growth parameters of tilapia (*Oreochromis niloticus*) (Brum *et al.*, 2017) and has beneficial effects on gene expression as an immune stimulant and antioxidant (Hoseinifar *et al.*, 2020). Singha *et al.* (2020)stated that ginger is an effective natural antibiotic and a natural immune stimulant. Ginger essential oil has been administered to tilapia @ 0.5 ml kg/diet that increases fitness, intestinal villi size, plasma cholesterol levels, leukocyte values, and other hematological variables, without affecting the metabolism or liver histomorphometric variables of tilapia (Chung *et al.*, 2021a). Ginger essential oil supplementation has been reported to improve the physiological status and intestinal morphology of tilapia (Brum *et al.*, 2018a). Brum *et al.* (2017) administered 5–15 mL kg/diet of ginger essential oil and noted increased growth of juvenile tilapia. The increase in growth was caused by the aroma of ginger, which increased the consumption of fish feed and affected weight gain(Brum *et al.*, 2018b). In addition, ginger's bioactive compounds improved the morphology of the digestive tract and mucosal integrity (Valladão *et al.*, 2017).

Ginger improves the physiological function, and fish health. Ginger also inhibits the action of free radicals and lipid peroxidation through its phenolic compounds, namely zingiberene, sesquiphellandrene (13.0%), and arcurcumene (Nyadjeu *et al.*, 2020). Chung *et al.* (2021a) reported that tilapia-fed ginger essential oil (0.5 mL kg/diet) increased the number of leukocytes, hemoglobin, and platelets, which contributed to the immunological defense of fish (Mohammadi *et al.*, 2020). Ginger essential oil supplementation can also stimulate leukocyte formation and contribute to increased nonspecific (or innate) immunity and reduced inflammatory cell production (Chung *et al.*, 2021b). Ahmadifar *et al.* (2019) reported that supplementation of 2 and 3% ginger feed in zebrafish (*Danio rerio*) significantly increased the immunoglobulin levels, alternative complement activity, lysozyme activity, amylase activity, and several immunological and biochemical responses, as well as the expression of relevant genes associated with antioxidant activity (phenols and flavonoids) and immune system. A similar observation was also reported on goldfish (*Cyprinus carpio*) by Mohammadi *et al.*, (2020). Ginger may increase the erythrocytes, hemoglobin, and hematocrit values which may increase the oxygen transport to body tissues (Copatti *et al.*, 2019). The effect of ginger supplementation on hematological variables has also been reported in carp (Mohammadi *et al.*, 2020). Ginger essential oil added to fish food increased the hematological variables of tilapia and prevented liver pathology and fat accumulation (Mohammadi *et al.*, 2020). An increase in fitness and nutrient utilization in sobaity bream due to the administration of a mixture of phyto-additives (garlic, ginger, and thyme in a ratio of 1:1:1) at a dietary inclusion rate of 30 g/kg Jahanjoo *et al.* (2018). Increased activity of digestive enzymes is correlated with increased digestibility of complex nutrients in fish (Singha *et al.*, 2020).

Cortisol and glucose are two indicators of stress in fish (Hajirezaee *et al.*, 2020). The cortisol is released from the internal tissues into the blood when fish undergoes stress. Cortisol, upon reaching the liver, caused glucose production via glycogenolysis (the breakdown of glycogen into glucose) or gluconeogenesis (the breakdown of protein into glucose) for the fulfillment of energy requirements. Ginger supplementation ameliorates the stress in fish, characterized by a higher plasma protein content and lower cortisol levels (Mohammadi *et al.*, 2020). Erythrocytes and hemoglobin are blood cells involved in the delivery of oxygen to body tissues and the transfer of toxic metabolites to the gills for excretion into the surrounding environment (Ahmadifar *et al.*, 2019). Low levels of erythrocytes and hemoglobin are closely related to disorders in the antioxidant system. Hoseini *et al.* (2018) reported that exposure to ammonia induced by oxidative stress can decrease antioxidant enzyme activity, which causes anemia in *Cyprinus carpio* fish. Ginger is a strong natural antioxidant (Hsiang *et al.*, 2013) that can protect red blood cells against hemolysis by free radicals, thereby prolonging the lives of fish. The fish-fed ginger extract showed an increase in total protein, albumin, and globulin contents in serum (Ahmadifar *et al.*, 2019). Leukocytes comprise the body armor that protects fish from pathogenic microorganisms. The number of leukocytes determines the physiological and pathological conditions of fish (Hoseini *et al.*, 2018). The higher leukocyte count in the ginger-supplemented fish group could be attributed to the presence of the bioactive compound zingerone, which can affect the spleen and thymus, and stimulate leukocyte secretion from these tissues. Significant increases in leukocytes have also been reported in *Lates calcarifer* (snapper), *Oncorhynchus mykiss* (rainbow trout), and *Huso huso* (beluga) (Hajirezaee *et al.*, 2020).

Ahmadifar *et al.* (2019) reported that supplementation with 3% ginger rhizome in powder form increased the Ig content of carp (*Cyprinus carpio*) serum. Fazelan *et al.* (2020) stated that ginger can activate immune cells, leading to increased immunity against harmful agents and stress. The presence of bioactive compounds in ginger rhizomes, including terpenes, oleoresin, zingiberol, zingiberon, zingiberene, gingerol, shogaol, zingerone, and paradol (Hsiang *et al.*, 2013; Mohammed *et al.*, 2020), has antioxidant (Si *et al.*, 2018), antibacterial (Beristain-Bauza *et al.*, 2019),

antiparasitic, and anti-inflammatory activities (Fu *et al.*, 2019). The physical structure (skin epithelium) and chemical structure (skin) defend fish from pathogens. The mucosal layer of the skin includes lysozymes, alkaline phosphatases, immunoglobulins, and proteases. *Labeo rohita* seeds supplemented with 0.2% ginger extract for 60 days increase skin mucosal immunity parameters (lysozyme, alkaline phosphatase, and total immunoglobulin). Skin mucosal immunity increases the immune response (Hajirezaee *et al.*, 2020). In addition to fish, the use of ginger has also been reported in shrimp. *Vibrio parahaemolyticus* is a bacterium that causes acute hepatopancreatic necrosis (AHPND) in the chitin layer of shrimp stomachs, causing necrosis (Soowannayan *et al.*, 2019b). The ethanolic extract of ginger (0.2 and 2 mg/ml) inhibits the formation of biofilms caused by AHPND (Soowannayan *et al.*, 2019a; Abd El-Hack *et al.*, 2021). Three potentially bioactive compounds known to occur in ginger extract (6-gingerol, 8-gingerol, and 6-shogaol) have also been reported to inhibit biofilms *in vitro* (Yatip *et al.*, 2018)

The insecticide dimethoate (DM), used to kill various larvae and adult insects, has side effects on fish, including reproductive disorders, oxidative stress, oxidative damage (Clasen *et al.*, 2018), and changes in various immune and biochemical parameters (Shadegan and Banaee, 2018) and. Dimethoate exposure reduces serum total protein and globulin levels and increases glucose, total cholesterol, alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase, urea, creatinine, creatinine kinase, hepatic malondialdehyde, total superoxide dismutase, and catalase. Ginger is reported to contain more than 50 antioxidant compounds associated with gingerols and diarylheptanoids and to play a protective role against pesticide toxicity (Anh *et al.*, 2020; Anwar *et al.*, 2020) and bisphenol A (BPA)-induced disorders (Mohammed *et al.*, 2020). Ginger supplementation also increases the antioxidant capacity of tilapia to overcome biochemical changes, chromosomal aberrations, and pathological changes induced by DM exposure (Soror *et al.*, 2021). In addition to being used alone, ginger supplementation in combination with other medicinal plant ingredients increases ginger's effectiveness (Ibrahim *et al.*, 2019). Turmeric combined with ginger or garlic in equal proportions at an inclusion level of 1% increases the growth, digestion, metabolism, antioxidant enzyme activity, and health status of *Labeo rohita* fish fry (Ibrahim *et al.*, 2019).

Conclusion: Ginger is a medicinal plant that has many benefits, especially in supporting health and increasing the productivity of livestock. The bioactive compounds found in the ginger rhizome are derivative functional essential oils, namely zingiberene, curcumin, geraniol, citronyl acetate, terpineol, linalool, borneol, neral, geranial, phenol, flavonoid, terpene, oleoresin, zingiberol, zingiberon, gingerol, and shogaelin. Additionally, it contains zingerone, organic acids, namely malice, citric acid, and tartaric acid, as well as flavones, phenolic acids, myricetin, quercetin, isoquercitrin, and tannic acid. These compounds are considered nutraceuticals and are known to have pharmacological effects on the animal body through activities as an antimicrobial, anti-inflammatory, anti-gastric, antidiarrheal, antioxidant, sedative, adaptogenic, immunomodulatory, antispasmodic, astringent, hepatoprotective, antiulcer, fungicide, and radical scavenging effects, as well as cyclooxygenase and lipoxygenase inhibitory potential. Therefore, the use of ginger as a natural antibiotic does not cause antibiotic resistance or residue problems compared to synthetic antibiotics, hormones, herbicides, and pesticides.

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