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Positive impacts of integrating flaxseed meal as a potential feed supplement in livestock and poultry production: Present scientific understanding

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ABSTRACT

When it comes to food and fiber production, flaxseed (*Linum usitatissimum*) has been around the longest. Oil makes up over 41% of a flaxseed's total weight; of that, more than 70% is polyunsaturated. Protein, dietary fiber, α-linolenic acid (ALA), flaxseed gum, and many other beneficial compounds are abundant in flaxseed meal (FSM). There is as much as 30% crude protein in FSM. Therefore, FSM can serve as a source of excellent protein for livestock. FSM increases the efficiency and effectiveness of livestock and poultry farming. FSM can be used as an essential protein feed component in cattle and poultry farming, boosting production and profitability. Because it contains anti-nutritional ingredients such as cyanogenic glycosides, tannins, phytic acid, oxalic acid and an anti-vitamin B6 factor, the use of FSM in livestock and poultry diets is restricted. Animal nutritionists have recently shown a growing interest in reducing anti-nutritional elements and boosting FSM's nutritional value. Recently, fermented FSM has been used to feed cattle and poultry; hence its dietary benefits have not yet been fully assessed. The present article, therefore, addresses the chemical make-up, bioactive components, anti-nutritional aspects, and positive impacts of FSM in livestock and poultry production.

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1 Introduction

In recent years, there has been an imbalance in the long-term supply and demand for conventional protein feed resources such as soybean meal. This has led to increased prices for feed and decreased long-term sustainability in the animal husbandry industry. Since traditional feed resources are limited, there is an immediate need to develop and employ non-conventional feed resources to improve the situation and reduce feed prices. In this scenario, different protein feed sources would be helpful in animal nutrition (Alagawany et al. 2015; Abd El-Hack et al. 2016; Deepak et al. 2020; Prakash et al. 2021a; Prakash et al. 2021b; Buttar et al. 2022; Chandran et al. 2022; Konavalov et al. 2022; Mitra et al. 2022).

One of the earliest oil-bearing crops cultivated worldwide was flaxseed. Flaxseed was grown on an estimated 3.39 million hectares globally between 2016 and 2020 (Cui et al. 2022). The top five nations producing flaxseed are Kazakhstan, the Russian Federation, Canada, China, and the United States of America, and global production has been hovering around 3000 kilotons for quite some time. Oil derived from flaxseed through pressing and refinement is a significant dietary supplement source of omega-3 PUFAs. Flaxseed meal (FSM) is a byproduct of processing flaxseeds for flaxseed oil, yet it still has a lot of nutritional value. The literature on FSM, however, is scant (Goyal et al. 2014). As with many other feed additives, FSM can be given to cattle and poultry as an alternative source of high-quality protein feed. Notably, there is the susceptibility of FSM to the variety of flax; origin climate; methods of oil extraction; and processes involved in production. These results in discrepancies in the nutrient composite and level of nutrition (Ye et al. 2022). While FSM has shown promise in the feed business, its widespread usage is hindered by cyanogenic glycosides (CGs), a potent anti-nutritional component in flaxseed. Reducing the amount of anti-nutritional elements in FSM increases its value as animal feed (Kumar et al. 2022; Kumari et al. 2022; Mueed et al. 2022).

Natural diets for livestock and poultry often include brown-seeded flaxseed (*Linum usitatissimum* L.), one of the most effective sources of omega-3 unsaturated fatty acids. As a source of n-3 PUFAs, FSM is considered superior to fish oil, corn, soybean or algae (marine). Polyunsaturated fatty acids (PUFAs) and α-linolenic acid (ALA), in particular, are abundant in most flaxseed species (Kajla et al. 2014; Lan et al. 2020; Chandran 2021). Flaxseeds are rich in ALA, an omega-3 fatty acid; flaxseed oil contains 45-52% ALA (Khan 2019). Almost every part of the flaxseed plant is helpful in some way for feeding livestock and poultry. Fibre extracted from the flax plant's stem is of the highest quality and durability. The seed provides easily absorbed proteins, anti-inflammatory lignans, and omega-3-rich oil. The oil and lignans found in flaxseed are essential for health, and its high-quality protein and soluble fiber are bonuses. It also has great potential as a phenolic compound supplier. Flaxseed is rising in popularity as a functional food ingredient thanks to its high lignan, fiber, and linolenic acid content. It has been discovered that lignans can prevent cancer. Flaxseed's lignan phytoestrogens and omega-3 fatty acids are being researched for their possible chemoprotective benefits in humans and animals (Singh et al. 2011; Mueed et al. 2022).

In the commercial livestock and poultry industry, flaxseed is commonly used as an ingredient added to chicken diets to provide healthier products and enhance the food market. However, the effect of flaxseed on the productivity of laying hens may vary with factors like the breed of hens, the age of the hens, the composition of their diet, and the duration of the experiment. The flaxseed cake (FC), leftover after flaxseed oil extraction, is a high-quality protein food for cattle and poultry containing anywhere from 10.5 to 31% protein. Its high ALA residual oil content benefits animal well-being (Xu et al. 2022). Depending on the seed strain and processing settings, the amount of residual oil in FC can be increased from approximately 1% to over 16%. This makes FC also a potential method for increasing the amount of omega-3 fatty acids in eggs, milk and meat (Khan 2019). Recently, there has been an extended mismatch in supply and demand for traditional resources of protein feeds, leading to rising feed costs and reduced livestock and poultry production sustainability. Given the current resource scarcity of feed, increasing the development and usage of unconventional feed resources is essential to compensate for this. Adopting a different animal protein diet may be helpful here (Gutiérrez et al. 2010). FSM's potential as animal feed can be improved by minimizing its anti-nutritional components (Kumar et al. 2022). This review article examines the anti-nutritional characteristics, nutritional components, and preliminary use of FSM in several livestock species, including layer and broiler chickens, beef cattle, dairy pigs, and swine.

2 Chemical composition and bioactive compounds in flaxseed meal

Many nutrients, such as omega-3 PUFAs, fiber, and protein, can be found in FSM. The breakdown of the flaxseed's chemical composition and chemical structures of the major bioactive components in flaxseed are illustrated in Figure 1 and Figure 2, respectively. FSM has a nutritional value similar to soybean protein due to its high crude protein concentration (35-40%). Soybean meal is a source of protein, but FSM could serve the same purpose. FSM is high in protein, ALA, and dietary fiber. Flax seed meal's nutrient profile and density might vary depending on factors such as the flax variety used, the weather at the seed's place of origin, the oil extraction method, and the manufacturing process (Prakash et al. 2021a; Prakash et al. 2021b).

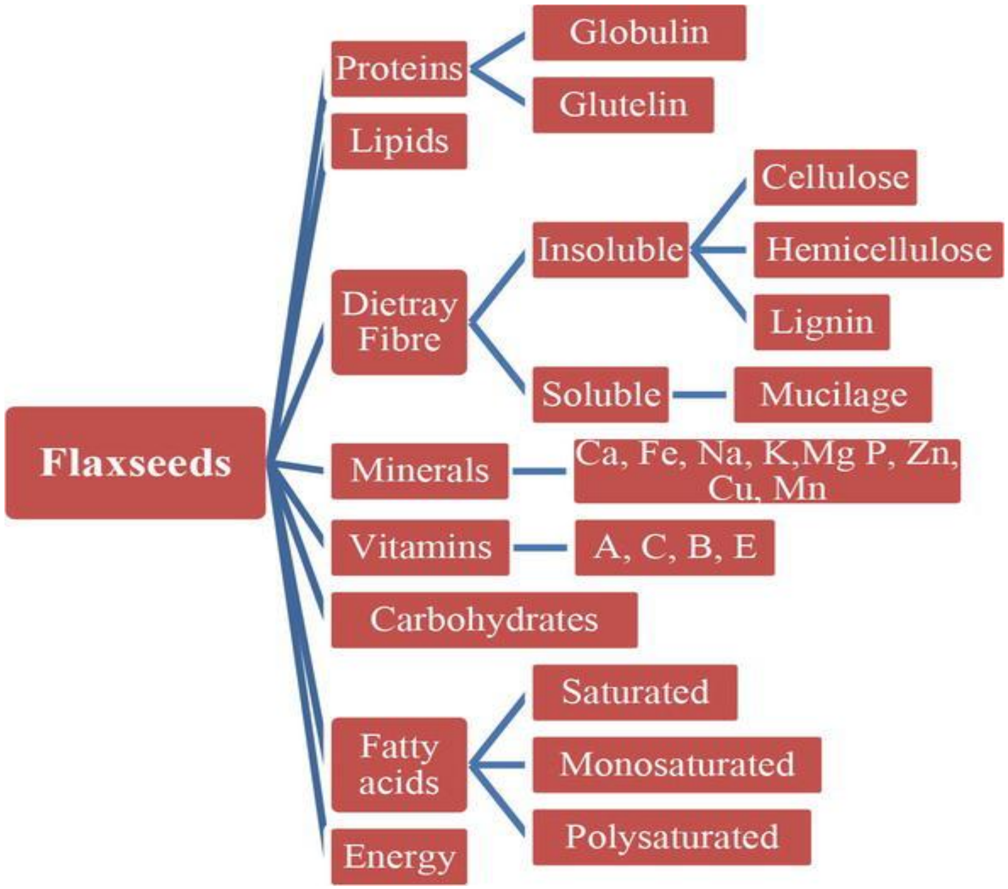

Figure 1 Chemical composition of flaxseeds

Proteins comprise roughly 23% of the weight of whole flaxseeds and as much as 35 to 40% of the weight of flaxseed meal, produced when the oil is removed. It has a good protein quality score because its amino acids are organized. A lysine-to-arginine ratio of 0.37 is heart-healthy because of its reduced atherogenic and lipidemic potential. Protein in FSM mostly takes the form of globulin and albumin (Xu et al. 2022). According to their solubility profiles, globulins and albumins can be compared to colinins and linins, respectively. A wide variety of amino acids, including those containing sulphur (like methionine and cysteine), branched-chain amino acids (like alanine, leucine, and isoleucine), and others (like lysine, tyrosine, and threonine), can be found in the human body. A large amount of amide is found in flaxseed because of its high concentration of storage proteins such as arginine, asparagines, aspartic acid, and glutamine (Wu et al. 2019; Mueed et al. 2022). There is an albumin found in plant seeds called conlinins. The sedimentation coefficient of 1.6-2 characterizes this peptide bond's composition. Increased disulfide linkages give these proteins a more structured form, with 26% helices and 32% structures making up their total molecular weight. Additionally, these albumins contain high concentrations of arginine, leucine, cysteine, alanine, and glutamine (Madhusudhan and Singh 1985; Mueed et al. 2022).

Proteins and peptides called cyclolinopeptides, orbitides, and linosurbs can be found in flaxseed. Around 25 different varieties of these compounds have been discovered (Dzuvor et al. 2018). Orbitides contain eight to ten different amino acids. Multiple therapeutic properties, such as immune suppression, anti-malarial, anti-tumour, and bone degeneration protection, have been attributed to these compounds (Shim et al. 2019; Mueed et al. 2022). Several health advantages have been linked to phenolic chemicals. Flaxseed contains many phenolic compounds, such as phenolic acids and lignans. Chlorogenic acid, vanillic acid, 4-hydroxy benzoic acid and coumaric acid were discovered to make up most of the phenolic acids in a Canadian flaxseed cultivar, with lignans making up the rest (Herchi et al. 2011; Bekhit et al. 2018; Mueed et al. 2022).

Flaxseed contains about 28% dietary fiber, which is made up of soluble and insoluble varieties. The soluble to insoluble dietary fiber ratio might be anything from 20:80 and 40:60. Fiber is the seventh most important nutrient for a healthy diet. Flaxseed dietary fiber has many recognized benefits, including enhanced satiety, higher fat excretion, relief from constipation, and a direct effect on the intestinal microbiota that results in the formation of short-chain

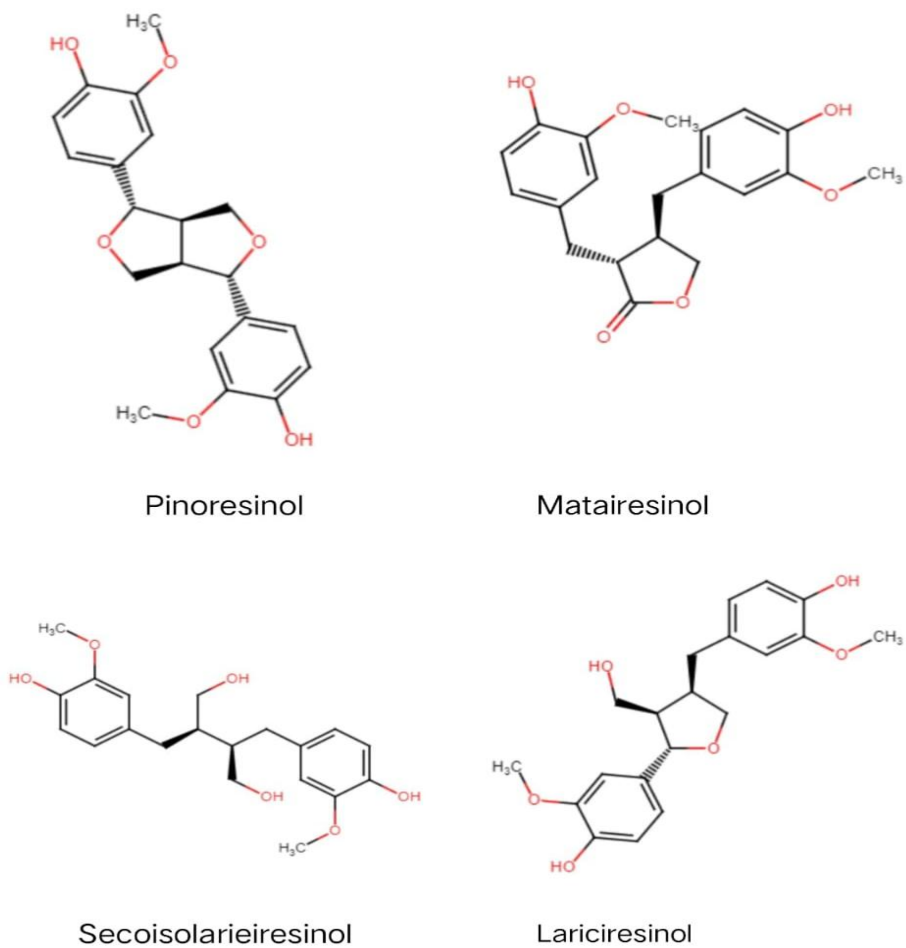

Figure 2 Chemical structures of major bioactive components present in flaxseed

fatty acids (SCFAs) that alter host metabolism. Because of its high fiber content, flaxseed is an excellent choice for supplementing livestock and poultry diets (Huang et al. 2022a).

Low-molecular-weight phenolic dimers derived from 2 and 3-dibenzylbutane are what we call lignans. Typically, they will be located in the flaxseed hull (Bekhit et al. 2018). Carotenoids, found in most fruits and seeds, are forty-carbon chemical compounds responsible for their red, yellow, and orange pigmentation and are also vitamin A precursors (Gul et al. 2015; Mueed et al. 2022). Carotene is a particularly important pigment since it has the highest pro-vitamin A activity (Yonekura and Nagao 2007). The carotenoid content of flaxseed is between 0.7 and 3.1 mg/kg. Carotenoids are crucial regarding flaxseed's high unsaturated lipid content because they protect against photooxidation. Based on their net charge, flaxseed mucilage (FM) polysaccharide fractions are acidic or neutral. Arabinoxylans are responsible for the neutral proportion that does not contain uronic acid, while galactose and galacturonic acid make up the bulk of the acidic percentage in modern pectic compounds (Liu et al. 2018).

Fatty acid composition is used to classify flaxseed oil (FO) into monounsaturated, polyunsaturated, and saturated varieties (Tvrzicka et al. 2011). The quantity of saturated fatty acids is low, but the number of unsaturated fatty acids is high (Yaqoob et al. 2016). Major components of FO extracted using petroleum ether were discovered to be linolenic acid (C 18:3, omega-3, 42.4%), linoleic acid (C 18:2, omega-6, 26.2%), palmitic acid (C 16:0, 12.9%), and stearic acid (C 18:0, 10.7%), as reported by Ishag et al. (2019). It appears that ALA is a PUFA that humans cannot generate themselves. ALA is converted into docosahexaenoic acid and eicosapentaenoic acid, two fatty acids crucial to body development, especially in the brain and skin (Yang et al. 2021). Because it contains such a high percentage of ALA (about 55% by weight), FSM is considered an excellent source of omega-3 PUFAs compared to soybean, fish oil, corn, or marine algae. Since the body cannot produce ALA in vivo, eating foods containing it is the only way to get enough (Mueed et al. 2022). The antibacterial, anti-inflammatory, and antioxidant effects of ALA have been the subject of several research, demonstrating their significance to livestock and poultry health. One of the n-3 PUFAs, ALA is crucial for agricultural purposes. Supplementing livestock and poultry diets with omega-3 PUFA improves their growth and fatty acid metabolism, increasing the dietary worth of animal products, and it also offers a wider variety of FSM from which to choose when creating functional livestock and poultry feed ingredients (Huang et al. 2022b).

About 8% of a flaxseed's dry mass comprises flaxseed gum (FSG), which is found primarily in the seed's outer hull. Neutral arabinoxylan and acidic rhamnogalacturonan make up the bulk of FSG, making it a heteropolysaccharide. There are unique physiological roles for flaxseed polysaccharides. In vitro, soluble FSG has antioxidant properties by neutralizing free radicals such as 1,1-diphenyl-1-picrylhydrazyl (DPPH) and 2,2-azino-bis-3-ethylbenzthiazoline-6-sulfonic acid (ABTS) to create more stable products. It has also been shown *in-vitro* that soluble FSG has a powerful ability to bind bile acids, reducing the flow of bile acids from the liver to the intestines. This, in turn, generates SCFA profiles that are helpful to the health of the gastrointestinal tract and reduce cholesterol levels (Xu et al. 2022; Ye et al. 2022). Important microbial metabolites of the organism, SCFAs, contribute to host metabolism by decreasing intestinal pH and may inhibit the growth of dangerous infections. Furthermore, FSG has the potential as a prebiotic for altering gut flora composition. By aiding in regulating lipid metabolism in the liver and reducing adipose tissue deposition, it can help prevent the detrimental effects of dyslipidemia in animals fed a high-fat diet. FSG may regulate gastrointestinal tract microbiota by reducing the Firmicutes/Bacteroidetes ratio, and it has been reported that feeding obese rats an optimum quantity of FSG can reduce obesity brought on by a high-fat diet. Therefore, FSG supplements can successfully treat and prevent diseases caused by oxidative damage, including weight loss and cancer protection (Attia et al. 2022; Mueed et al. 2022).

3 Anti-nutritional factors in flaxseed

Hydrocyanic acid, phytic acid, and anti-vitamin B6 (anti-VB6) are three anti-nutritional factors found in FSM that may have adverse effects on animals and restrict its use in animal diets even though it

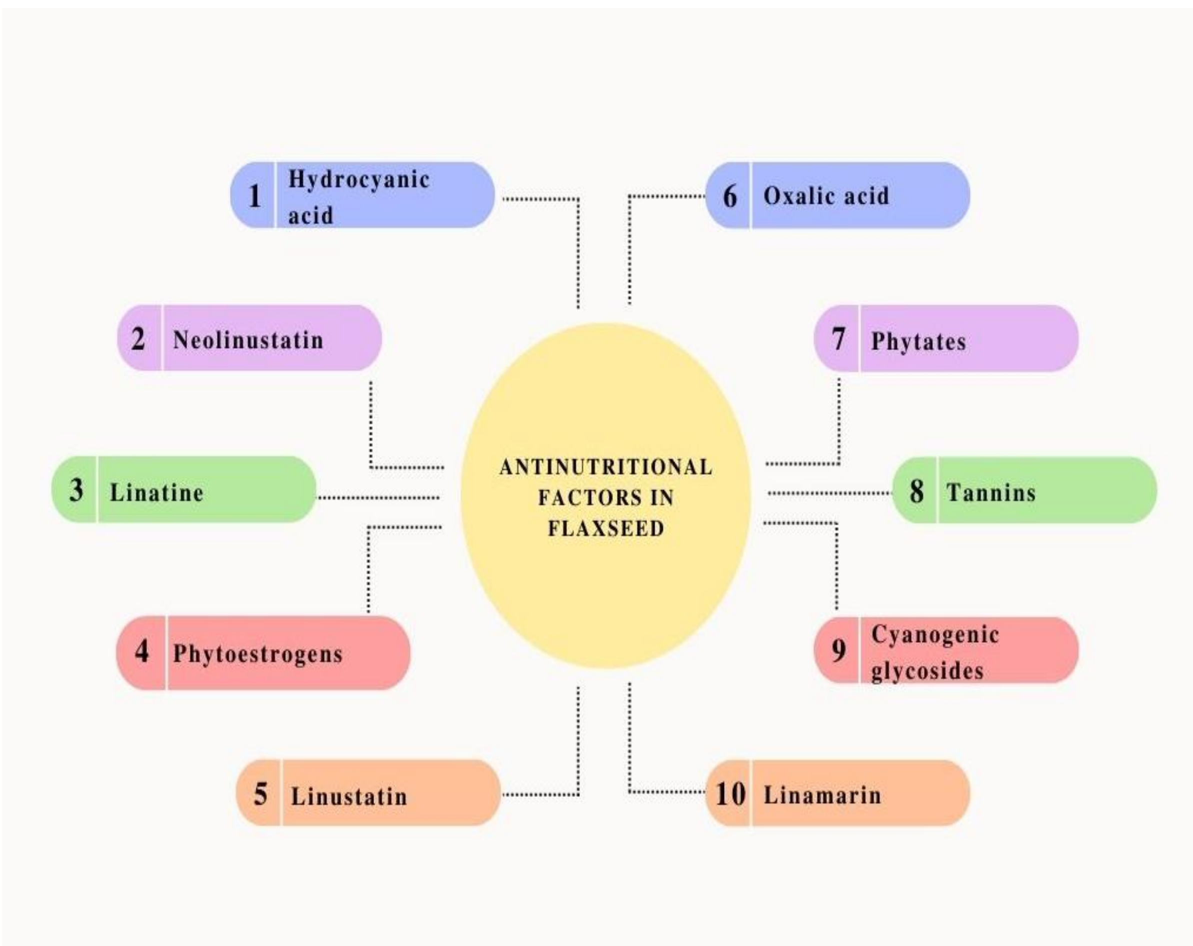

Figure 3 Major anti-nutritional factors present in flaxseed meal

contains many valuable additives and is a new source of protein feed in animal husbandry (Huang et al. 2022a). Flaxseed meal has many vital components that are detrimental to nutritional value, as depicted in Figure 3.

Cyanogenic glycosides (CGs) are present in flaxseed at concentrations ranging from 264–354 mg/100 g. Cynates are a naturally occurring component of plant matter, and the hydrolysis of cyanates results in the formation of hydrogen cyanide. Cynide (CN), when present in high numbers at a low dose, will be hazardous to humans on repeated exposure because it inhibits the cytochrome coxidase system involved in the respiratory chains (Enneking and Wink 2000). The total CG content of flaxseed ranges from 0.74 to 1.60 g/kg of cyanogenic nitrogen. The extraction method of flaxseed that presses the seeds results in a CG content of 394.99 mg/kg in the resulting flaxseed meal (Zhai et al. 2019). This finding is highly encouraging. Whole flaxseed contains between 250 and 550 mg/100 g of cyanogenic glycosides, whereas linustatin and neolinustatin have respective concentrations of 207 and 174 mg/100 g of seed. According to Park et al. (2005) research, the HCN concentration of linustatin and neolinustatin was reduced by more than 85% when flaxseed was cooked for more than two hours at a temperature of 200 °C. Because CGs and β-glucosidase are located in different parts of the FSM, it is not feasible for them to come into touch with one another. As a result, CG is non-toxic under normal conditions and does not emit HCN. However, once the animal has adequately chewed, β-glucosidase is presented with CG and makes complete contact with it. After this point, toxic HCN is created by enzymatic hydrolysis, which is likely detrimental to the animal's health. Extremely high concentrations of CG in food can readily cause acute poisoning, resulting in death between ten and twenty minutes after ingestion. In addition, chronic poisoning, goiter, growth retardation, neurological problems, and other undesirable effects can be caused by feeding animals feed containing CG over an extended period (Vetter 2000).

Plant tissues store and release oxalic acid and its salts as end metabolites. Because of the potential for adverse health effects, the amount of oxalic acid in the average person's diet has long been a source of concern. Oxalic acid is an absorption inhibitor linked to many health problems, including kidney stones, low calcium levels, and low iron levels (Palaniswamy et al. 2002). For humans, ingesting 5g or more of oxalic acid would be dangerous, but even low quantities have an adverse effect. Studies have indicated that a serving of flaxseed powder has between two and ten milligrams of oxalate (oxalate content), while a serving of roasted flaxseed has less than two milligrams of oxalate. The concentrations were 6.43–19.40 mg/100g for whole cooked samples, 9.03–11.90 mg/100g for row soy products, and 4.3–7.99 mg/100g for cooked samples. In moderation, these items are fine for healthy people to eat, but they should be avoided by those who suffer from gout, rheumatoid arthritis, kidney illness, or chronic vulvar pain (vulvodynia).

A significant anti-nutritional component in FSM is phytic acid, with concentrations of 23 to 33 g/kg FSM (Oomah et al. 1996). Phytic acid has a potent chelating activity and can form stable complexes with mineral ions, proteins, and starch directly or indirectly (Akande et al. 2010). It has been shown to decrease piglets' apparent ileal digestibility (Woyengo et al. 2012) and to promote broilers' elimination of endogenous minerals and amino acids (Cowieson et al. 2004).

Tannins have an extraordinarily intricate and diverse chemical makeup. Proanthocyanidins and gallic acid polyesters are two categories that describe these compounds (Mahmut and Ayhan 2002). Flavanols are the source of concentrated tannins, while sugar esters (often glucose) are the source of hydrolyzable tannins (Bartosz et al. 2017). Researchers have found trypsin inhibitors in flaxseed; however, their activity is much lower than in soy and rapeseed (Bhatty 1993).

The concentration of anti-VB6 in FSM ranges from 177 to 437 μg/g and is a dipeptide made up of proline and glutamine. Anti-VB6 factors can interact with the enzyme produced when vitamin B6 is phosphorylated. If the latter happens, animals will have trouble absorbing and using vitamin B6 because the loss of its physiological function has a knock-on effect on vitamin absorption and usage. Several studies have shown that feeding animals and birds an excessive amount of FSM can result in symptoms like decreased appetite, apathy, and neurological abnormalities, but FSM is still widely utilized in cattle and poultry production. These unfavourable effects can, however, be wiped out by properly incorporating vitamin B6. To that end, adding an FSM to the animal feed ration necessitates adding vitamin B6 in sufficient quantities (Mueed et al. 2022; Ye et al. 2022).

4 Beneficial Effects of Flaxseed in Livestock and poultry production

Particularly crude protein and energy are present in high quantity in FSM and thus can be used as animal protein feed. Replacement of soybean meal (SBM) in animal feed with other plant protein feed is a long-term goal and this goal can be achieved by using FSM (Hao et al. 2020). The high levels of ALA and DFs in FSM have garnered a lot of interest because of their potential to enhance the health of cattle and poultry significantly. FSM is a significant and valuable source of high-quality protein. FSM has been studied to increase the omega-3 PUFA content of animal products, but little is known about its potential usage as a dietary protein component in livestock and poultry feeding (Mueed et al. 2022). Table 1 summarises how flaxseed is used in the livestock and poultry feed industries, and Figure 4 depicts the potential positive impacts of flaxseed in animal husbandry and poultry.

Table 1 An overview of the applications of flaxseed in livestock and poultry

Animal	Source and quantity provided	Outcome	References
Dairy cattle	Whole flaxseed – 6 to 8%	Postpartum energy balance is enhanced	Gandra et al. (2016)
	Whole flaxseed- 4.8%	Enhanced liver antioxidant enzymatic activity and consumption of dry matter	Do Prado et al. (2016)
	Ground flaxseed – 6.3 to 7.3%	Concentration of omega-3 PUFA in milk is boosted.	Petit and Côrtes (2010)
	Flaxseed – 6.5%	Fatty acid content is increased in milk	Caroprese et al. (2010)
Beef cattle	Whole flaxseed- 3.6 to 18%	The accumulation rate of PUFAs differ between 14.3% and 17.6%	Mach et al. (2006)
	Flaxseed- 5%	Percentage of omega-3 PUFA increased in intramuscle fat.	Alberti et al. (2014)
Swine	Crushed flaxseed -6%	Enhanced ranges of omega-3 PUFA in adipose and muscular tissue	Kouba et al. (2003)
	Flaxseed – 2.5%	Notable improvement omega-3 PUFA growth in meat and fat level	Đordevi´c, et al. (2016)
	Flaxseed – 27.8%	Act as a source of protein for animal feed	Ndou et al. (2018)
	FSM – 1.5%	Considerably affects carcass fatty acid composition	Eastwood et al. (2009)
Broilers	FSM- 10%	FSM of 10%, boosted the meat's ALA content	Kumar et al. (2019)
	FSM- 5 to 15%	Fatty acid content is increased in meat	Mridula et al. (2011)
Layers	Flaxseed- 10%	Egg quality is increased and IgY content of egg yolk is enhanced	Cherian and Quezada (2016)
	Flaxseed- 5 to 15%	Concentration of omega-3 PUFA present in egg yolk was enhanced	Scheideler and Froning (1996)
	Flaxseed 10%	Concentration of both DHA and omega-3 PUFA content in eggs were increased	Mattioli et al. (2017)

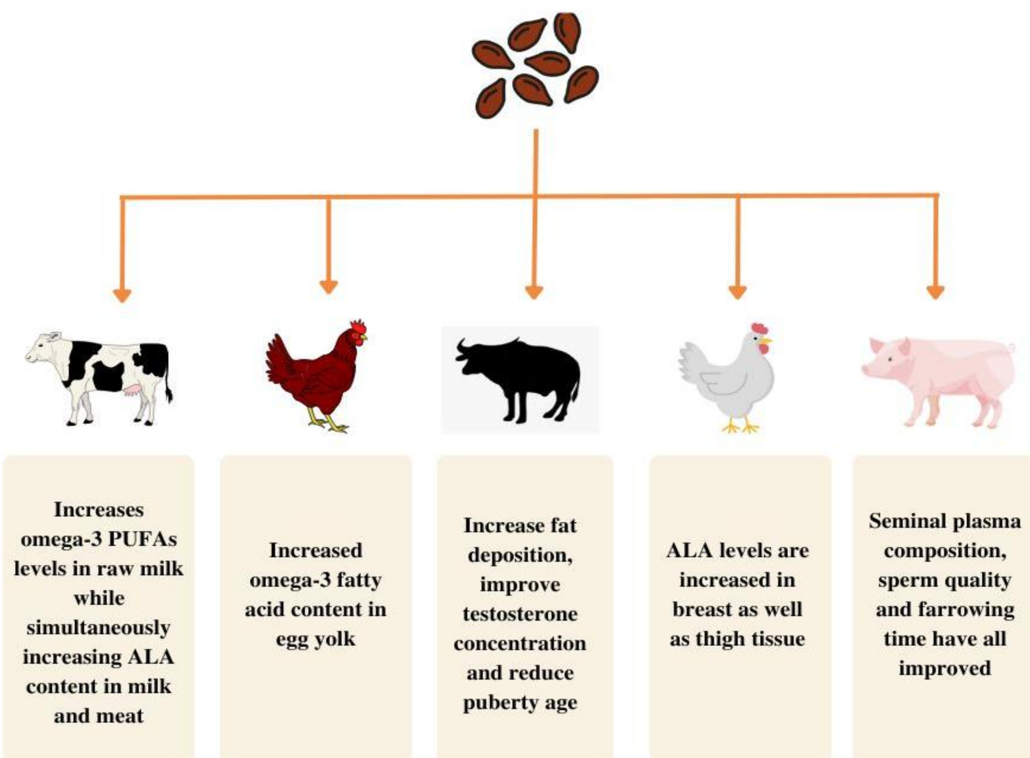

Figure 4 Beneficial effects of flaxseed meal upon integration as a potential feed ingredient in the livestock and poultry production

5 Beneficial Effects of Flaxseed on dairy cattle production

Most research and development efforts devoted to the beneficial effects of FSM in ruminants have focused on dairy cattle. Feeding dairy cows properly is essential during milk production since diet has a major impact on milk's nutrient profile. It's common knowledge that the omega-3 PUFAs found in flaxseed positively affect human health. Therefore, there is growing interest in animal production in the generation of milk high in omega-3 PUFAs by supplementing the diet with flaxseed to improve human health. Numerous studies have demonstrated that feeding flaxseed to dairy cows is an effective strategy to increase milk's omega-3 PUFA content. Several studies have also focused on the period between the end of gestation and the beginning of lactation in dairy cows. At this time of year, dairy cows are especially vulnerable to developing metabolic and viral problems or possibly dying from them (Zachut et al. 2010; Gandra et al. 2016; Huang et al. 2022a). Again, due to the richness of flaxseed in n-3 PUFA, it is often introduced into the diet of dairy cows to increase the n-3 PUFA level in milk. Hence, the introduction of both whole and ground flaxseeds in the dairy cows' diet has been done to enrich the milk from the nutritional aspect (Isenberg et al. 2019; Huang et al. 2022b). Commonly used for its fatty acid content, flaxseed may help early nursing calves achieve a more positive energy balance. Several studies have found that dairy cows whose diets included flaxseed throughout the transition period had greater increases in liver glycogen and antioxidant activity following calving and lower triglyceride levels. It's possible that this could help in the battle against liver fat. The fatty acid profile of milk can be changed, lipid accumulation in the liver can be reduced, and fatty liver disease can be avoided if dairy cows are fed flaxseed, as has been proven in previous studies (Petit and Côrtes 2010; Zachut et al. 2010; Jahani-Moghadam et al. 2015; Ye et al. 2022). All of these advantages suggest that flaxseed may play a beneficial function in the well-being of cows.

Milk's nutrient content is boosted when cows are fed flaxseed, leading to other positive changes in milk's composition that are good for human health. Feeding extruded flaxseed (EF) to cows has been observed to increase the quantity of PUFA in their milk (Zachut et al. 2010). In addition to whole flaxseed, flaxseed oil (FO) and FSM can also be fed to cows. After FO is taken out, all that's left is FSM. FSM is high in protein and fiber while being low in crude (Gagnon et al. 2009). Goodridge et al. (2001) found that lactating dairy cows given either 1.76 or 3.53 pounds of flax-protected casein per pound of milk fat generated, and Ward et al. (2002) found that a meal consisting of salt (or linoleum, a flax cultivar), flax, and canola at 8 percent DM increased milk fat production in lactating dairy cows. Goodridge et al. (2001) found that a linear increase in ALA levels in milk occurred in response to a rise in flax consumption. Feeding EF to Holstein Friesian cows accelerated their ovulation and reduced the number of cyclic follicles they experienced. In a study by Jahani-Moghadam et al. (2015), pregnant heifers fed EF, and those not fed EF had identical open rates, service rates, and conception rates. Flax seed was used as a supplement for three types of cattle (Holstein Friesian, Jersey, and Friesian-Sahiwal crossbred) for nine weeks. Parameters related to semen quality were monitored weekly. Several characteristics of fresh semen were evaluated, including its volume, concentration, mass motility, and percentage motility (Khan et al. 2015). The quality of sperm collected after being frozen has been shown to increase in cattle (Gholami et al. 2010). It is possible to boost the omega-3 fatty acid content of fortified dairy products by feeding whole, unprocessed flaxseed to dairy cows, and thus could have a positive impact on human health. Enterolactone may affect milk production if the carbohydrate composition of FSM-based diets offered to dairy cows is changed (Brito et al. 2015). Methane generation can be reduced by eating a diet enriched with flax seeds (Li et al. 2012).

6 Beneficial Effects of Flaxseed on beef cattle production

Rumen bacteria are killed off when microbial lipases in cattle combine with rumen lipids to create PUFAs (Prieto et al. 2017). To reduce the harmful consequences, these microorganisms biohydrogenate PUFAs into less harmful saturated fatty acids, most notably 18:0. Absorption occurs in the lower stomach, where the remaining PUFA biohydrogenation intermediates (PUFA-BHI) are incorporated into tissues like muscle. Therefore, beef is abundant in PUFA-BHI, such as vaccenic acid and rumenic acid (Scollan et al. 2006). Increasing the proportion of omega-3 PUFAs in intramuscular fat and decreasing the omega-6/ omega-3 PUFA ratio increased fat deposition when young bulls were fed a diet containing 5% flaxseed (Barahona et al. 2016). Feeding EF before hay in a non-total mixed diet (non-TMR; non-total mixed ration) would increase the amounts of 18:3 omega-3 fatty acid (linolenic acid) and the BHI in beef while decreasing the degree of biohydrogenation in the rumen (Vahmani et al. 2017). To boost the nutrient density of beef, flaxseed is often fed to cattle. This increases the amount of omega-3 PUFA in the meat. The fat deposition was increased, the fraction of omega-3 PUFAs (primarily ALA) contained in intramuscular fat increased, and the ratio of omega-6/omega-3 PUFA content decreased by 5% flaxseed was added to the concentrate diet for young bulls (Alberti et al. 2014). Including 10% whole flaxseed in beef cattle diets has improved beef's organoleptic qualities, such as reducing fat odour and enhancing beef flavor (Barahona et al. 2016). Whole flaxseed supplementation in Holstein Friesian cattle dramatically increased omega-3 PUFAs in beef (Mach et al. 2006). When beef cattle were fed with Hereford 907 gram/day, Angus cattle 454 gram/day for 3 days, followed by 907 gram/day of ground, flaxseed resulted in increased omega-3 PUFA levels and peroxisome proliferator-activated receptor gamma (PPARγ) gene expression in the longissimus muscle. When 5% flaxseed was fed, it increased omega-3 PUFA content (mostly ALA) in intramuscular fat. 3.6%, 11.2%, and 18% of whole flaxseed enhanced the deposition rate of PUFAs in beef ranging from 14.3% to 17.6%. Also, 10 - 15% of flaxseed decreased feed intake with no negative impacts. Although excessive amounts of FSM will limit feed intake, adding flaxseed or FSM to the diets of beef cattle is generally seen as beneficial.

7 Beneficial Effects of Flaxseed on swine production

Since pigs only have one stomach, their dietary ALA is more readily available for Absorption since it is not biohydrogenated before reaching the small intestine. Linolenic acid was found in increasing amounts and showed a linear increase in both back fat and bacon over time. Grower pigs fed a diet containing up to 15% FSM had their linolenic acid content increase from 11 mg/g back fat to 48 mg/g back fat (Mueed et al. 2022; Xu et al. 2022). Leterme et al. (2007) found that pigs fed diets containing up to 15% full-fat flaxseed or flaxseed flour continued to thrive as long as the feeds were well-balanced in nutrient supply and digestible amino acids.

By lowering prostaglandin F2α (PGF2α) and prostaglandin E2 (PGE2) production, omega-3 PUFAs supplementation in early pregnancy in gilts may increase the likelihood of successful embryo development and birth. In addition, eicosapentaenoic acid (EPA) concentrations in the piglets' liver, muscle, and adipose tissue can be enhanced by supplementing the sow's diet with flaxseed oil, boosting omega-3 PUFA diets during lactation increases subsequent litter size born, both live born and total piglets born. Previous research into the effects of feeding sows and their piglets a diet containing 6.5% FSM during late pregnancy and lactation indicated that adding FSM could boost omega-3 PUFAs and lower the omega-6/omega-3 fatty acids ratio in the sows' milk within 20 days of lactation. It may also help piglets recover from weaning and grow faster afterwards (Sun and Kim 2020; Xu et al. 2022). There is an improvement in the IgG level in milk along with improved growth performance of the suckling piglets by supplementing omega-3 PUFAs (coated) in the sow diet using flaxseed oil (Xu et al. 2022).

According to Kaur et al. (2021), there were no adverse effects when sows' diets were supplemented with flaxseed at a rate of 0.5% of the dry matter from day 1 of lactation until the day of the subsequent farrowing. The sows' body composition parameters, hormonal balance, capacity for procreation and non-esterified fatty acids (NEFAs) concentration may have even improved. The study also found that varying the amount of expanded flaxseed in a sow's diet had no discernible influence on litter size, mean birth weight, or mean daily growth but did alter milk fatty acid composition and omega-3 PUFA status in newborn and adult piglets. According to the literature, feeding sows flaxseed or FSM during the last few months of pregnancy and while they are nursing their piglets can have positive effects on the health of the sows and the piglets, as well as increase economic efficiency (Mueed et al. 2022; Xu et al. 2022). However, feeding the sows the right amount of FSM is important to prevent any adverse side effects on the piglets.

8 Beneficial effects of flaxseed on broiler production

Feeding flaxseed to broilers 14 days before slaughter improves their meat quality. To increase omega-3 fatty acid enrichment without negatively impacting animal health, chicken breeders are advised to give their birds FO or powdered flaxseed 14-21 days before slaughter. Flaxseed consumption has been linked to increased accumulation of docosahexaenoic acid. Chicks fed 10% of their total dry matter as pelletized flaxseed gained weight and ate more. The nitrogen and energy efficiency gains from pelletizing are undeniable. Increased feed density and broken grain cell walls from damp heat improve digestibility. The villus height increased significantly, suggesting beneficial effects on duodenal and jejunal morphology that may improve nutrient absorption (Hernandez 2013; Attia et al. 2022). Broilers' FA profiles were significantly enhanced after being fed a 10% FSM diet for around 3 weeks, and the amount of cholesterol and fat in the meat was reduced, which is good for the birds' health (Xu et al. 2022). Breast meat might have more omega-3 PUFAs deposited on it if flaxseeds are fed to the animal.

Chicken breast and thigh with flax seed added to have more omega-3 fatty acids, less blood protein, and more liver enzymes (Xu et al. 2022). Feed conversion rate (FCR), protein efficiency ratio, and energy efficiency ratio were significantly increased in poultry birds fed with 5g and 10g flaxseed/kg feed meal. Including 2% FO in broiler feed has reduced the lag in embryonic mortality (Pliego et al. 2022). Adding 15 percent flax to broiler feed increased mean body weight while decreasing digestible energy and ether extract content. Broilers fed flax-enriched diets had the highest quality carcasses, with a high percentage of muscles and low levels of abdominal fat. It also led to an 11% rise in iron in the pilon muscles. Improved intestinal morphometric measures and decreased feces viscosity were only two of the many ways broiler chickens' digestive health benefited from adding 10 - 15% flaxseed to their meals. Feeding broiler chickens between 21 and 42 days of age a diet with 15% flaxseed increased body weight, feed intake, and various slaughter characteristics. The protein and nutrient content of chicken muscles were also enhanced. Preliminary data from production suggests that using flaxseeds in one's diet is beneficial, as doing so increases the nutritional content of meat (Zajc et al. 2020).

9 Beneficial effects of flaxseed on layer production

Linolenic acid, a rich source of flaxseed, has been shown to raise eggs' omega-3 fatty acid content significantly. In the designer food sector, eggs are routinely fortified with linolenic acid from flaxseed to ensure they are safe for human consumption (Beheshti and Cherian 2017). Since laying hens' gizzards can crush coarse seed, it stands to reason that flaxseed, which has a softer seed coating, may also be pulverized sufficiently for digestion. Yolk omega-3 PUFA content may be significantly enhanced to 6.83% when flaxseed content is increased to 15% without affecting layer omega-3 PUFA content. Efficient Absorption of dietary omega-3 PUFAs by layers allows the fatty acids to be transported to the egg yolk. PUFA omega-3-enhanced eggs and meat products have been made with flaxseed for quite some time. Egg production and consumer acceptance of marketed eggs may be impacted by flaxseed's flavor and aroma when consumed by layers at levels above 10%. Incorporating flaxseed into feed benefits egg production by increasing the nutritional value for human health, not because of the processing cost (Scheideler and Froning 1996; Attia et al. 2022).

There was no adverse effect on laying parameters when flaxseed was added to the diet of laying hens. On the other hand, adding flaxseed has been demonstrated to affect hen production performance in several trials negatively. The omega-3 PUFA content of egg yolk was increased after being supplemented with flaxseed at 5, 10, and 15%. The percentage and weight of egg yolks had decreased, while ALA and EPA levels had increased dramatically when 10% whole product or ground flaxseed was included in layers feed. Egg quality was improved, and the amount of healthy ALA in eggs was increased due to flaxseed supplementation, which increased the level of egg yolk antibodies (IgY) in the yolk. Adding 10% flaxseed to a chicken's diet has increased the amount of DHA in the egg yolk. Enzyme supplementation of 10% flaxseed boosted feed efficiency and mitigated flaxseed's deleterious effects. Immune function, lipid profiles, yolk color, and reproductive success were all improved with supplementation of 12% soaked flaxseed meal (Gregory et al. 2013; Xu et al. 2022).

When it comes to removing the flaxseed's anti-nutritional components, extrusion is a simple and inexpensive method. Flaxseed grains' bioavailability and Absorption can be improved by using an extrusion technology that releases the intercellular oil found in these seeds while eliminating most of their anti-nutritional components at high pressure and temperature (Chandran 2021). Although EF has far less tannin and hydrocyanic compounds, feeding it to layers at more than 20% decreased laying performance. It has been established that adding an EF product to layer feed raises the amount of omega-3 PUFAs in egg yolk without reducing overall egg production. Metabolizable energy in EF diets dropped with increasing EF addition rates, and chickens fed EF didn't eat more to make up for the difference. However, the animals consumed more of the feed when the flaxseed (10% and 20%) feeds had less metabolizable energy than the control diet. Increased omega-3 PUFA were seen in the egg yolks of chickens fed either of the EF diets (Attia et al. 2022; Mueed et al. 2022). The yolks of chickens fed EF contained higher omega-3 PUFA because of the addition of ALA and DHA, but ALA deposition appears more significant. LinPRO, a flaxseed supplement, boosted omega-3 PUFA content in the yolk by 96% and 154%, respectively, when given to layers at 7.5% and 15% concentrations. No adverse effects on layer performance or egg characteristics were seen when EF was supplemented at up to 22.5% in the diet of layers. Energy utilization is impacted by the variation in EF between meals (i.e. 15% and 22.5%) (Huang et al. 2018; Prakash et al. 2021b; Xu et al. 2022). This is mostly due to lower levels of metabolizable energy in the flaxseed-fed meals.

It is interesting to note that when flaxseed meal is added to the diet of brown-layer hens, the digestibility of crude protein decreases, while at the same time, there is a rise in the production of eggs and the performance of the hen (Popescu et al. 2021). This was found in research conducted by Popescu et al. (2021).

Mild changes in adult laying hens' body weight have been seen after introducing flax seeds into their diet. In contrast to managed hens, EF-fed layer hens used less metabolizable energy because they lost body weight. Anti-nutritional elements such as oxalic acid, cyanogenic glycosides, tannins, and phytic acid can be found in flaxseed. Mucilage, a type of water-soluble polysaccharide found primarily in flax seeds, may improve the viscosity of digestive juices. The quality and quantity of eggs laid by hens fed flaxseed for an extended period may also suffer. Adding 10% flaxseed to the diet of laying hens has been shown to produce eggs with health benefits for consumers (Prakash et al. 2021a; Prakash et al. 2021b; Mueed et al. 2022; Xu et al. 2022).

10 Possibilities for utilizing fermented flaxseed meal in livestock and bird production

Despite the widespread reporting of FSM's inclusion in livestock and poultry feeds and the purported benefits of doing so, there are strict limits on the amount of FSM that may be added to an animal's diet without causing harmful consequences. Producers are more likely to include FSM in animal diets if they see proof that it can considerably replace soybean meal and cut feed costs without severely impacting animal growth performance. Anti-nutritional components in FSM are being degraded through microbial fermentation, and this process is already underway with promising results (Deepak et al. 2020; Chandran 2021; Kumar et al. 2022; Kumari et al. 2022). The current issues with integrating FSM in Livestock and poultry production can be overcome if the technology for the microbial fermentation of FSM utilized in animal and poultry feed develops to its full potential. Microbial fermentation technology can break down the anti-nutritional components in FSM, allowing for the full utilization of the feed's nutritional potential and positively affecting animal palatability, immunity, and productivity. Additionally, this can eventually raise the percentage of FSM as an alternative to soybean meal in animal diets. When fermented, however, FSM's many functional components (PUFAs, fiber, etc.) work together with the probiotic bacteria to great effect. The value of FSM will be increased, and improved feeding effects will be obtained since the original beneficial nutrients will be preserved and various beneficial microbial metabolites may also be produced (Huang et al. 2022a; Mueed et al. 2022; Xu et al. 2022).

Conclusions

FSM can be utilized as an essential protein feed component to improve protein feed consumption in livestock and poultry husbandry. Livestock and poultry should not be given more than the recommended amount of flaxseed meal as a supplement, as doing so can have adverse effects. In addition to its potential application as a novel protein feed element in place of soybean meal, FSM may also be improved through microbial fermentation for increased use in cattle and poultry production. However, it's essential to remember that research into the nutritional value of fermented FSM in Livestock and poultry is still in its infancy, and its use is still quite uncommon. There is still a need for a thorough chemical study of fermented FSM and a database on the dietary value of fermented FSM to establish an accurate feed formula. More study is required to confirm the usefulness of fermented FSM, show that it has no detrimental effects on feed conversion rate (FCR) and growth performance, and determine the optimal amount to add to animal feed. Important factors influencing the application of fermented FSM include the identification of strains with a high capacity for beneficial metabolites production, deterioration of nutrient-depleting anti-nutrient factors, improving the raw materials' nutritional value, and elevating the fermentation process to a higher level so that its large-scale production does not adversely affect the overall fermentation effect.

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