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The Biological, Healthy, and Dietary Advantages of Using Flaxseed Byproducts in The Diet of Ruminant Animals and The Methods for Extracting Oil and Fiber from Flax Plant

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Abstract: Flaxseed is an excellent source of α-linolenic acid, lignin, protein, and viscous fiber and contains important quantities of micronutrients. The oil is extracted from the seeds using a chloroform and methanol mixture, resulting in a high oil content of 66.6%, which includes approximately 55% omega-3 fatty acids essential for maintaining animal health. Flaxseed oil also contains a high amount of lignin, which is primarily responsible for its physiological benefits in animals due to its antioxidant activity, acting as a hydroxyl radical scavenger. Flaxseed carotenoids also capture singlet oxygen to scavenge lipid-free radicals and function as secondary antioxidants. Flax meal is a by-product formed after the oil extraction of seeds and is given to cattle diets as an extra source of protein. Seeds of flax are better when crushed before being added to animal feeding. Therefore, flaxseed and its oil constituents play a significant role in the nutrition of farm animals.

Keywords: α-linolenic acid, healthy benefits, ruminant animals, flaxseed oil, flax fiber

The biological profits of flaxseed

Flaxseed is one of the oldest oilseed crops, having been used for food and fiber for millennia. Flaxseed is grown worldwide for its oil, fiber, and health benefits. Flaxseed is currently farmed for its oil and fiber in India, Holland, Russia, and Britain, despite its Egyptian origins (**Soni *et al.*, 2016). Berglund (2002)** states that of the two million metric tons of flaxseed produced, Canada accounted for 33%, followed by China (20%), the US (16%), and India (11%). Between 2016 and 2020, 3.39 million hectares of flaxseed were cultivated globally on average (**Cui *et al.*, 2022**). The United States of America, Canada, China, the Russian Federation, and Kazakhstan are the top five producers of flaxseed. Flaxseed oil is an important source of additional n-3 polyunsaturated fatty acids. The flaxseed meal, produced after oil extraction, offers significant nutritional value for farm animals. It provides essential nutrients, including protein and fiber, which contribute to their overall health and growth (**Shim *et al.*, 2015**). Flaxseed contains a significant amount of polyunsaturated fatty acids, comprising up to 52% of its total fatty acids. Additionally, it is rich in plant lignin, with levels reaching up to 13 mg per gram. The rising interest in α-linolenic acid, lignin, protein, and dietary fiber led to its increased use in animal feed (**Carter 1993**). **Zhang *et al.* (2008)** reported that the extraction of flaxseed seeds using chloroform and methanol resulted in a high oil content (66.6%), which included α-linolenic acid (ALA), an omega-3 (n-3) fatty acid (55.76%); linoleic acid (15.18%); and oleic acid (16.76%). The high concentration of omega-3 (alpha-linolenic acid, ALA) and lignan (secoisolariciresinol diglucoside or phytoestrogens) in flaxseed oil is primarily responsible for its physiological benefits. Animals must obtain omega-3 fatty acids from food or other sources since their bodies are unable to manufacture them on their own. The animal body converts the fatty acid α-linolenic acid (ALA) into eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These omega-3 fatty acids (ALA, EPA, and DHA) are associated with improved animal health **(Pan *et al.*, 2012).**

The dietary profits of flaxseed

Whole flaxseeds provide higher fiber content, while ground flax allows better nutrient absorption. Although experts prefer ground flax, both should be included in the diet for optimal effects. Nutrient content per 100 g of flaxseed meal typically has 534 K calories, 18.3 g of crude protein, 42.2 g of crude fat, 28.9 g of carbohydrates, 27.3 g of crude fiber, 1.55 g of total sugars (1.15 g sucrose and 0.40 g glucose), 6.96 g of water and 3.72 g of ash (**Council of Canada, 1997**). In addition, flaxseed has 3.66 g of total saturated fatty acids, 7.53 g of total monounsaturated fatty acids and 28.73 g of total polyunsaturated fatty acids (including 22.8 g of omega-3 fatty acids, primarily ALA). Flaxseed is the best plant source of omega-3 fatty acids. It has a low amount of saturated fatty acids (9%), a moderate amount of monounsaturated fatty acids (18%), and a high amount of polyunsaturated fatty acids (73%), according to **Touré and Xueming (2010)**. **Petit (2003)** also states that the protein content of flax ranges from 18.8% to 24.4%, with 41% oil, 20% protein, and 28% dietary fiber. Flaxseed protein has high levels of important amino acids. The composition of flaxseed protein (g/100 g protein) isolates are isoleucine 15.31%, glutamine 13.90%, valine 13.18%, tyrosine 11.22%, aspartic acid 5.33%, asparagine 5.76%, tryptophan 4.95%, cysteine 4.45%, phenylalanine 4.32%, glycine 3.94%, methionine 3.40%, glutamic acid 2.96%, lysine 2.70%, serine 2.19%, praline 1.75%, histidine 1.39%, threonine 0.79%, arginine 0.74%, alanine 0.64%, and lucien 0.37% (**Sharma and Saini, 2022**). Flaxseeds are especially rich in phosphorus, magnesium, and thiamine. Flax seeds contain 9% saturated fat, of which 54% consists of omega-3 fatty acids, along with 5% palmitic acid, 18% omega-9 fatty acids (oleic acid), and 6% omega-6 fatty acids (linoleic acid, LA). Flaxseed oil contains 13% omega-6 fatty acids and 53% omega-3 fatty acids **(USDA, 2015**). Flaxseed is a rich source of essential minerals, including calcium, iron, magnesium, phosphorus, sodium, zinc, copper, and selenium **(Baby, 2022**). Flaxseed contains 0.24% calcium, 0.43% magnesium, 0.62% phosphorus, 0.83% potassium, 50 ppm iron, 30 ppm manganese, 270 ppm sodium, 40 ppm zinc, and 10 ppm copper (**Nutrient Data Laboratory, 2003).** Flaxseed has the potential to be beneficial in a diet since it includes lignans, polyphenols like lutein and zeaxanthin, and antioxidants like vitamins C, E, and K. Flaxseed also provides various vitamins, such as thiamine, riboflavin, niacin, vitamin B6, folate, and choline **(Baby, 2022**). Flaxseed contains antioxidants such as vitamin C, lutein and zeaxanthin, vitamin E, and tocopherols, which are potent antioxidants. Vitamins of flaxseed meal (mg/kg as fed) according to **the Nutrient Data Laboratory (2003**) are 0.20, 7.50, 2.90, 33.00, 14.7, 6.00, 1.30, 15.12, 9.04 and 0.41 for Vitamin C (beta carotene), thiamin, riboflavin, niacin, pantothenic acid, vitamin B-6, folate (folacin), choline, vitamin E (alpha-tocopherol) and biotin, respectively. The same authors also discovered that γ-tocopherol, at a concentration of 9.04 mg per 100 grams of seed, is the predominant isomer found in Canadian flaxseed cultivars. The authors also observed that the quantity of seed oil is related to both the overall levels of tocopherols and the specific presence of γ-tocopherol. Flaxseed contains beta-carotene and lutein, and carotenoids may scavenge singlet oxygen and function as secondary antioxidants. Carotenoids can function as chain-breaking antioxidants by absorbing lipid-free radicals when singlet oxygen is absent (**Belitz *et al.*, 2004**).

The dietary benefits of flaxseed oil

Chemical analysis of flaxseed oil as a percentage shows 22.8% crude protein, including 11 amino acids (42 g/100 g protein); 4.78 megacalories/kg net energy; and minerals, including 0.24% calcium, 0.43% magnesium, 0.62% phosphorus, 0.83% potassium, 50 ppm iron, 30 ppm manganese, 270 ppm sodium, 40 ppm zinc, and 10 ppm copper, as shown by **Lardy and Anderson (1999).** Both flaxseed oil and milled seeds have better bioavailability than whole seeds, and flaxseed oil is believed to contain more α-linolenic acid than milled seeds (**Shakir and Madhusudan, 2007**). The physiological benefits of flaxseed oil are mainly due to the high levels of omega-3, lignin (SDG), phytoestrogens, and lignans. Animals cannot produce omega-3 on their own; therefore, animals must obtain omega-3 from their diet. According to **Kitts *et al.* (1999**), flaxseed contains phytoestrogens that have antioxidant properties, particularly as hydroxyl radical scavengers and lignin (a type of soluble fiber), is responsible for these benefits. Lignans, polyphenols, dietary fiber, vitamins C, A, E, and F, and minerals are among the many bioactive elements found in flaxseeds, which are also utilized as a source of dietary fiber in animal feed (**Rizvi *et al.*, 2020**). Three distinct types of omega-3 fatty acids are essential for the diets of animals, as they play a crucial role in their nutrition. Flaxseed oil is rich in linoleic acid (ω-6) and α-linolenic acid (ω-3), both of which play a role in regulating prostaglandin synthesis (**Raole and Raole, 2022)**. Furthermore, flaxseed oil is the highest plant source of these chemicals, including 53% ALA and 19% oleic acid. Flaxseed oil has an excellent n-6: n-3 fatty acid ratio of about 0.3:1 due to its high ALA content (**Nowak and Jeziorek, 2023**).

The health benefit of flaxseed

Flaxseed oil contains significant amounts of omega-3 fatty acids, which are essential for promoting animal health. Flaxseed oil has hypolipidemic, cholesterolemic, and atherogenic effects in animals. Flaxseed lignin may influence cholesterol homeostasis **(Cunnane *et al.*, 1993**). Dietary flaxseed reduces glomerular damage and delays the decline of renal function while improving blood pressure and plasma lipids. Dietary flaxseed greatly enhances the functioning of the renal system (Parbtani and Clark, 1995). Given that diets high in omega-3 reduce lymphocyte proliferation and the immune response in healthy animals, a high intake of omega-3 may be beneficial for those suffering from autoimmune diseases (**Kelly, 1995**). Omega-3 fatty acids lower blood pressure overall, reduce triglycerides and cholesterol, and lower blood pressure in individuals with hypertension (**Wright *et al.*, 1998).** Giving steers diets supplemented with flaxseed may improve their immune systems and protect them from heat stress (**Farren *et al.*, 2002**). The animal body, via metabolism, may transform α-linolenic acid into DHA (ω-3) and EPA (ω-3). Flax is rich in polyunsaturated fatty acids, especially linoleic acid (LA), a necessary omega-6 fatty acid, and α-linolenic acid, an essential omega-3 fatty acid. These two polyunsaturated fatty acids are essential for the functioning of mammalian bodies. In flaxseeds, linoleic acid and α-linolenic acid account for 57% and 16.0% of total fatty acids, respectively (**Morris, 2003).** According to **Zhang *et al.* (2008**), the three ω-3 fatty acids ALA, EPA, and DHA, are associated with various health benefits, such as protection against hypertension, autoimmune diseases, and neurological disorders. Omega-3 and omega-6 fatty acids come in two different varieties. Linolenic acid, EPA, and DHA are three types of essential omega-3 fatty acids that are crucial for nutrition (**Kajla, 2015**). The most abundant plant source of the lignin precursor secoisolariciresinol diglycoside (SDG) is flaxseed. The rumen or hindgut microbes transform SDG into mammalian phytoestrogens, which may be used in hormone replacement treatment, potentially providing benefits such as alleviating menopausal symptoms and reducing the risk of certain hormone-related cancers (**Maddock *et al.*, 2005**). Flaxseed, which is high in oleic and linolenic acids, significantly improves the integrity of cell membranes (**Kasote, 2013).** Lignans (SDG), proteins, soluble and insoluble fibers, ω-3 fatty acids, short-chain polyunsaturated fatty acids, and other antioxidants are all abundant in flaxseed (**Lu *et al.*, 2020**). These compounds are physiologically active and function as hypocholesterolemic agents (**Singh *et al.*, 2011).** Enterolactone and enterodiol, which offer various health benefits, can be produced in the intestines by bacteria that modify the SDG content of flaxseed **(Touré and Xueming, 2010).** Consuming flaxseed oil can lower low-density lipoprotein, one of the primary risk factors for heart disease (**Pan *et al.*, 2012).**

Impotence of α-linolenic acid

1. The potential benefits of α-linolenic acid

Flaxseed contains omega-3 fatty acids, which are essential for the production of EPA, a hormone-like substance needed for immune response (**Maddock *et al.*, 2004**). The potential benefits of alpha-linolenic acid (18:3 n-3) are converted into EPA (20:5 n-3) and DHA (22:6 n-3). This conversion takes place in the liver and consists of a series of alternating desaturation steps, which involve adding double bonds, and elongation steps, which involve adding carbon atoms. The conversion of EPA to DHA requires an additional elongation, a second desaturation, and a peroxisomal oxidation step (**Anderson *et al.*, 2009**). Alpha-linolenic (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) are examples of omega-3 fatty acids that have demonstrated significant health benefits. However, the animal body's incapacity to manufacture these fatty acids has necessitated the use of goods like flaxseed or its oil. α-linolenic acid acts as a precursor to longer-chain omega-3 fatty acids, such as EPA and DHA. Numerous studies have clearly shown the physiological and biological significance of omega-3 fatty acids in animal diets. The animal body can convert the ALA fatty acid to the beneficial EPA and DHA. Improved animal health is associated with three omega-3 fatty acids: ALA, EPA, and DHA. Dietary omega-3 fatty acids are essential for synthesizing eicosanoids, which regulate various biological processes, improve the absorption of fat-soluble vitamins, and help maintain the integrity of cell membranes **(Ponnampalam *et al.*, 2001).**

2. The role of α-linolenic in lipid metabolism in the liver

The primary mechanisms through which α-linolenic acid, a crucial omega-3 fatty acid, influences lipid metabolism in the liver include reducing oxidative stress, altering gene expression associated with fat production and oxidation, diminishing hepatic fat storage, and directly impacting hepatocyte function and metabolic signaling pathways. α-linolenic acid acts as a precursor to longer-chain omega-3 fatty acids, such as EPA and DHA. In summary, dietary ALA is an effective hepatoprotective agent that reduces hepatic lipid accumulation by simultaneously inhibiting fatty acid synthesis and promoting fatty acid oxidation **(Takic *et al.*, 2024).** Using flaxseed as a source of fatty acids during the transition period may alter the fatty acid composition of milk, reduce lipid accumulation in the liver, and potentially prevent the development of fatty liver disease.

3. The role of α-linolenic acid in the regulation of the inflammation

Omega-3 fatty acids (EPA and DHA) regulate inflammation by replacing pro-inflammatory omega-6 fatty acids in cell membranes, reducing the production of inflammatory chemicals like eicosanoids and cytokines, and producing anti-inflammatory molecules called resolvins (**Morshedzadeh *et al.*, 2021**). Omega-3 fatty acids also inhibit key inflammatory signaling pathways and modulate immune cell function to reduce chronic inflammation. Omega-3s produce anti-inflammatory alternatives **(Calder, 2013).** Flaxseed oil provides anti-inflammatory properties that are often advantageous to animals, along with high-quality protein, soluble fiber, *α*-linolenic acid, lignans, *ω*-3 fatty acids, flavonoids, phytoestrogens, and phenolic compounds. Flaxseeds provide various applications and health benefits due to their rich nutritional profile, which includes properties that help, reduce inflammation and prevent oxidative damage (**Hussain *et al.*, 2021**).

Lignans role in hormonal pathways

Flaxseed has significant levels of lignans, a type of polyphenol chemical obtained from plants. Following consumption, intestinal bacteria convert lignans into enterolignans, mainly enterolactone and enterodiol, which share structural similarities with the hormone estrogen. Because of their structure, they function as phytoestrogens, affecting androgen metabolism and interacting with hormonal pathways by imitating, inhibiting, or modifying the activity of estrogen. These pathways may involve alterations in estrogen metabolism, variations in sex hormone-binding globulin levels, inhibition of key steroidogenic enzymes, and modulation of estrogen receptor activity **(Baldi *et al.*, 2023).** Furthermore, the potential for lignin, an estrogen component found in flaxseed oil, to transform into estradiol 17β may explain the rise in estradiol 17β levels after flaxseed oil therapy (**Habeeb *et al.*, 2021b).** The bioactive substances, especially lignans, possess anti-inflammatory and antioxidant properties and may influence lipid metabolism in the liver (**Rajan *et al.*, 2023**).

Techniques for extracting oil from flaxseeds

Extraction of flaxseed seeds by chloroform with methanol produced a high oil level, including α-linolenic acid, an omega-3 (n-3) fatty acid, which is essential for maintaining animal health. Flaxseed oil is derived from flaxseed using a specific industrial process, regardless of whether its beneficial components have been removed.

Cold Pressing: The ideal method for extracting oil from flaxseed is to use a cold press machine, which uses mechanical pressure without heat to create high-quality oil. For the purpose of removing sediment, just put dried flaxseeds into a portable mechanical screw-type press, collect the oil, and allow it to settle for two to three days. By avoiding excessive heat, this technique preserves nutrients. Clean the seeds of any debris before running them through the press. The resulting oil may appear hazy. Keep the sediment in a cold, dark, airtight container ideally made of glass for a few days to allow it to sink to the bottom. About 30% of the seed weight is produced.

Hot Pressing: This method involves roasting seeds and pressing them at high temperatures. This technique produces a higher yield but can damage delicate nutrients.

Solvent Extraction: This method uses chemical solvents like hexane to remove the oil and is often used for industrial, high-volume, or non-food-grade oil.

Aqueous Enzymatic Extraction: This method uses water and enzymes at low temperatures, retaining high levels of bioactive ingredients. For the commercial extraction of flaxseed oil, the aqueous enzymatic technique was appropriate.

Flax meal is regarded as a by-product created and utilized in animal feeding after the oil is extracted from the seeds.

The process of extracting fiber from flax plants

The outer layer of the flax plant's stem is the natural source of flax fibers. A ring of flax fibers is situated between the inner part of the stem and the outer bark. Flax fibers are natural, soft, glossy, and flexible; bundles of the fiber resemble blonde hair and are less elastic but stronger than cotton fiber (**Dhirhi *et al.*, 2015**). Additionally, flax fiber is a raw material used in the production of high-quality paper, rolling paper for cigarettes, tea bags, and robes, as well as printed banknotes. Numerous woven and non-woven ends are made from flax. Due to their potential applications in biological contexts, particularly in wound healing, flax fibers, which are also utilized in various industrial and durable products, have garnered increased attention (**Singh *et al.*, 2011).** A procedure known as retting is used to produce flax fibers. The fibers are sorted, dried, and spun into yarn or thread following retting (**Dhirhi *et al.*, 2015**). The phases in the multi-stage flax fiber extraction process that separate the usable fibers from the plant stem include harvesting, retting, and mechanical extraction (**Feleke *et al.*, 2023**). The following are the multi-stage procedures:

1. Harvesting: The entire plant, including the roots, is usually removed from the ground rather than chopped to produce the longest, best-quality fibers. When the seeds are starting to turn brown and the plants are yellow, harvesting takes place.
2. Rippling is the method used to extract the seed pods from the stalks.
3. Retting (separation) is the process of breaking down the pectin that holds the fibers to the woody stem using water and microorganisms since stems are immersed in ponds or water tank for one week.
4. Spreading & Drying: Following the retting process, the stems need to be completely dried in the sun for one week. During this drying period, the stems are collected and stacked.
5. Breaking & Cleaning: The dried, brittle stalks are crushed into tiny bits by a flax breaker machine, which separates the inner woody core from the stronger, flexible fiber bundles. The process of removing the remaining woody core from the fiber is done by beating it with a wooden knife.
6. Hackling (scotching): The fibers are combed, a process known as, using sharp, metal-toothed combs. This technique aligns the short, tangled waste fibers with the long, high-quality fibers, referred to as “line”, in preparation for spinning.
7. Spinning: To produce a smooth and durable thread, the long fibers are spun into linen yarn. This process may sometimes involve a wet-spun method.

Use the byproduct of the oil extraction process in ruminant feeding

Flaxseed meal (flaxseed cake) is a high-quality protein feeder for cattle and contains between 10.5 and 31% protein (**Kajla *et al.*, 2015**). Flaxseed proteins can be hydrolyzed by proteases to produce biologically active peptides, which play important physiological roles in the body with anti-inflammatory and antioxidant properties (**Marambe *et al.*, 2008**). Consequently, flaxseed meal is a wonderful source of protein for animals. Flaxseed meal improves the animal farming's efficacy and efficiency. In cow farming, flaxseed meal may be utilized as a crucial protein feed component to increase output and profitability (**Rajan *et al.*, 2023**). Flaxseed meal is regarded as a wonderful source of omega-3 PUFAs since the body cannot generate ALA in

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vivo; the only way to obtain enough is to consume foods that contain omega-3. The significance of ALA's antibacterial, anti-inflammatory, and antioxidant properties for cattle health has been emphasized in multiple research studies (**Mueed *et al.*, 2022**).

About 28% of flaxseed consists of dietary fiber, which is available in both soluble and insoluble forms. The ratio of soluble to insoluble dietary fiber can vary, ranging from 20:80 to 40:60.. The seventh most crucial ingredient for a balanced diet is fiber. Increased satiety, increased fat excretion, relief from constipation, and a direct impact on the intestinal microbiota that produces short-chain fatty acids that change host metabolism are just a few of the well-known advantages of flaxseed dietary fiber. Flaxseed is a great option for enhancing the diets of cattle due to its high fiber content (**Huang *et al.*, 2022a).** Numerous studies have examined ALA's antibacterial, anti-inflammatory, and antioxidant qualities, highlighting its importance for the health of cattle. Adding omega-3 PUFA to livestock diets enhances their improvement and fatty acid metabolism, which increases the nutritional value of animal products. Omega-3 PUFA also provides a greater range of flaxseed meal to select from when making functional livestock feed ingredients (**Huang *et al.*, 2022b**). Due to its potential to significantly enhance cow health, flaxseed meal's high ALA and dietary fiber levels have garnered significant interest. Research has shown that flaxseed meal can boost the amount of omega-3 polyunsaturated fatty acids in animal products (**Rajan *et al.*, 2023**). By adjusting the diet and using by-products, flaxseed meal can boost the economic efficiency of cattle production (**Rajan *et al.*, 2023**). Dairy cows are the main focus of flaxseed meal applications. The diet of dairy cows significantly influences the nutritional content of milk, highlighting the importance of providing appropriate feed during the milk production phase (**Xu *et al.*, 2022**). The n-3 polyunsaturated fatty acids present in flaxseed are known to be beneficial for human health. Flaxseed meal is an essential protein feed component that can increase protein feed consumption in livestock production. Consequently, the production of n-3 PUFA-rich milk through dietary supplementation with flaxseed to enhance human health has garnered increasing attention in the field of animal production (**Petit and Cortes, 2010**). To prevent negative consequences, livestock should not be supplemented with more flaxseed meal than is advised. Flaxseed cake, recognized for its rich nutritional profile, presents a promising by-product that can be utilized to create value-added products. Due to its varied nutritional profile, bioactive ingredients, and possible health advantages, flaxseed cake has attracted a lot of attention. Additionally, the residual fat extracted from flaxseed cake is a significant source of omega-3 fatty acids **(Talwar *et al.*, 2025).**

Benefits of incorporating flaxseed into the diets of ruminant animals

1. Blood biochemical analysis

Several research studies indicate that flaxseed and its oil positively influence various components of blood composition. Rabbits that received 100 and 200 µl of omega-3 orally showed significantly higher levels of total protein, albumin, globulin, uric acid, creatinine, T3, and progesterone (Habeeb *et al.* 2021a). In contrast, the amounts of total cholesterol, triglycerides, and lipids decreased. **Habeeb *et al.* (2021b)** found that the concentrations of glucose, total cholesterol, high-density lipoprotein, and low-density lipoprotein are dramatically decreased while the concentrations of albumin, globulin, total protein, T_3, and estradiol-17 increase when flaxseed oil is fed to sheep. The author attributed it to enhanced dry matter intake and improved digestibility in the feed. The α-linolenic acid found in flaxseed is converted by the body into EPA and DHA, which help lower cholesterol levels and thereby enhance heart health **(Baby, 2022).** Flaxseed oil has many health advantages, such as decreasing triglycerides and bad cholesterol **(Hadi *et al.*, 2020).** Frequent consumption of flaxseed may improve lipid profiles and help lower blood pressure, fasting glucose, and the insulin resistance index. The decrease may be attributed to the fact that flaxseed oil, which is high in α-linolenic acid, encourages the release of cholesterol into bile. This process reduces the intrahepatic cholesterol pool and enhances cholesterol synthesis and turnover **(Morise *et al.*, 2004).** Alpha-linolenic acid decreases hepatic lipid buildup in animal livers by promoting oxidation, reducing fatty acid synthesis, and lowering cholesterol production **(Murase *et al.*, 2005).** The lignans found in flaxseed extract have been shown to lower LDL cholesterol levels, total cholesterol levels, and glucose concentrations **Pan *et al.*, 2012).** Rabbits fed 2% flaxseed oil had significantly higher HDL (high-density lipoprotein) levels and significantly lower triglycerides, LDL (low-density lipoprotein) cholesterol, and total cholesterol. Flaxseed oil added to the diet of rabbits lowers blood cholesterol levels by reducing the production of endogenous LDL. Additionally, omega-3 fatty acids decrease plasma triglyceride levels **(Eid *et al.*, 2010).** Feeding omega-3 to rabbits induces hypolipidemic conditions due to its reduction of HDL and total cholesterol. Alpha-linolenic acid reduces total cholesterol, LDL cholesterol, and VLDL cholesterol in the group given ground flaxseed powder **(Francisco, 2017).** Blood levels of HDL significantly increased while serum levels of triglycerides and total cholesterol significantly decreased as a result of flaxseed oil's high polyunsaturated fatty acid content, low saturated fat content, and phytosterol content (**Sahoo and Ranveer, 2015**). By lowering blood triglycerides, cholesterol, and atherogenic indices, flaxseed improves cardiovascular health markers in cattle and contributes to improved animal health (**Rajan *et al.*, 2023).**

2. Beef cattle production.

Although flaxseed's health advantages for animals have been known for more than a century, its use in animal feeding has just lately come to light. Flaxseed meal can strengthen the immunity of the animal, which enhances production efficiency and the flavor of related animal products **(Habeeb *et al.* 2021a).** Daily body gain and dry matter intake in sheep significantly increase when using flaxseed oil supplementation orally. The improvement may be related to enhancements in nutrient digestibility, the nutritional content of feed ingredients, and an increase in feed consumption and improved feed conversion (**Habeeb *et al.*, 2021b).** Rabbits fed diets containing 2% flaxseed oil showed higher feed conversion and nutritional values for total digestible nitrogen and digestible energy than those on the control diet **(Habeeb *et al.* 2021a).** Oral administration of 100 and 200 µl of omega-3 led to a significant increase in the weight of pregnant rabbits, as well as the size and weight of their litters at birth **(Xu *et al.*, 2022).** Ground or rolled flax has demonstrated better performance than whole flax in terms of gain and efficiency. This suggests that processing flax, whether by grinding or rolling, is essential for enhancing growth and nutrient absorption (**Maddock *et al.*, 2005).** The scientists found that feeding feedlot heifers a diet containing 8% flaxseed increased the levels of omega-3 fatty acids in fresh beef, boosted available energy, and enhanced growth efficiency **(Beauregard *et al.*, 2023).** Both soluble and insoluble fibers are present in flaxseeds. The mucilaginous fiber improves nutrient absorption in the intestines and promotes faster food passage (**Anderson *et al.*, 2009).** According to **Delgado *et al.* (2018),** lowering the n-6/n-3 ratio enhanced feed efficiency and improved the rabbits' capacity to retain nitrogen and digestible energy in their bodies. Flaxseed is regarded as a valuable protein source in cow diets due to its relatively high protein content of 22.8% **(Kajla *et al.*, 2015).** Adding flaxseed to the diet of animals enhances feed palatability because various active components in flaxseed meal can positively interact with beneficial bacteria during the fermentation process. This interaction increases the value of flaxseed meal and generates cooperative microbial metabolites that improve feeding effects and preserve the original beneficial nutrients **(Maddock *et al.*, 2012).** Flaxseed is very nutritious, contains a lot of protein, and is a great source of vital fatty acids and energy. In addition, the benefits of feeding flaxseeds to cattle may stem from the mucilage, which may aid in postponing digestion and providing more time for nutrients to be absorbed **(Goodridge *et al.*, 2001).** Ruminal fermentation can be affected by supplementation. Using flaxseed to modulate this fermentation has been shown to decrease populations that produce methane (**Rajan *et al.*, 2023).**

When microbial lipases in cattle interact with rumen lipids, they generate omega-3 polyunsaturated fatty acids and simultaneously reduce the presence of rumen bacteria (**Prieto *et al.*, 2017).** These microbes transform bio-hydrogenated polyunsaturated fatty acids into less harmful saturated fatty acids, thereby reducing their negative effects. The remaining polyunsaturated fatty acid bio-hydrogenation intermediates (PUFA-BHI) are absorbed in the lower stomach and integrated into muscle and other tissues. Consequently, beef has a high PUFA-BHI content (**Scollan *et al.* 2006**). When young bulls were fed a meal containing 5% flaxseed, fat deposition increased when the proportion of omega-3 polyunsaturated fatty acids in intramuscular fat increased and the ratio of omega-6 to omega-3 polyunsaturated fatty acids decreased (**Barahona *et al.* 2016**). Flaxseed is frequently used in beef cattle to enhance the nutritional content of the meat by encouraging the deposition of n-3 PUFAs in muscle tissue **(Xu *et al.*, 2022).** Similarly, adding 5% flaxseed to young bulls' concentrate diet encouraged fat deposition, which raised the proportion of n-3 PUFAs in intramuscular fat and lowered the n-6/n-3 PUFA ratio (**Alberti *et al.*, 2014**). The rate of n-3 PUFAs in the meat of Holstein cattle rose linearly with the amount of whole flaxseed added to the diet (Mach *et al.*, 2006). It is recommended to use a maximum of 5% flaxseed in cattle concentrate feed, 7.5% flaxseed meal (FSM) in calf diets, and 20% flaxseed in yearling feed for the sake of animal safety **(Authority, 2007).**

3. Dairy cattle production

Lactating animals are the main target of flaxseed meal applications. Dairy cows must be fed an appropriate diet when they are producing milk since food has an impact on the nutritional content of milk **(Moats, 2015).** Flaxseed oil added to the diet of lactating animals may enhance milk production and increase the levels of the beneficial fatty acid α-linolenic acid in milk fat. Milk from cows given flax had greater protein content. Furthermore, the α-linolenic acid level in milk increased linearly as more flax was added to the diet. The rumen biohydrogenation process increases the amount of dietary α-linolenic acid that is transferred to α-linolenic acid in the milk. However, the efficiency of this transfer does not always rise linearly because a small percentage of dietary α-linolenic acid, due to hydrogenation, reaches the mammary gland **(Mueed *et al.*, 2022a).** Flaxseed feeding reduced the quantity of milk and energy-corrected milk by 1.8 kg/d and 1.4 kg/d, respectively, and resulted in lower levels of milk protein and casein (**Maddock *et al.*, 2012**). α-linolenic acid levels in milk from dairy cows that were fed an 8% flaxseed diet increased, while the protein content decreased. However, milk output and fat content remained unaffected **(Gandra *et al.*, 2016).** When flaxseed oil was added to cows' feed, there was an increase in milk production, a decrease in the percentages of saturated fatty acids, and a higher proportion of beneficial fatty acids **(Do Prado *et al.*, 2016).** The negative energy balance of early-lactating cows may be lessened by flaxseed, which is commonly used as a source for fatty acids (**Gandra *et al.*, 2016).** Improving the health of the animal is closely related to the advantages of flaxseed's function **(Pi *et al.*, 2016).** Flaxseeds are considered an excellent feed component to enhance dietary nitrogen absorption, as they contain approximately 32% oil. Flaxseed oil is known for its high concentrations of oleic and linoleic acids, which serve as effective antiprotozoal agents. This property enhances the efficiency of dietary protein consumption **(Nowak and Jeziorek, 2023).** Feeding flaxseed oil, a rich source of polyunsaturated fatty acids, to dairy cows alters the fatty acid composition of their milk, enhancing its nutritional benefits for humans. Polyunsaturated fatty acids are generally considered healthier for humans compared to saturated fatty acids. In addition, feeding polyunsaturated fatty acids, such as flaxseed, which is high in α-linolenic acid, to milk fat has increased the quantity of omega-3 fatty acids to fulfill animal health needs **(Badinga and Caldari-Torres, 2017).** Supplementing dairy cows with omega-3 fatty acids may help strengthen their immune systems and control how animals' immune systems function. Omega-3 improved the overall health of high-yielding dairy cows, which are susceptible to immunological deficits soon after calving **(Moallem *et al.*, 2020).** The effect of adding flaxseed, which contains α-linolenic acid, to the diets of pregnant cows demonstrated that ALA increased milk production and the levels of unsaturated fatty acids **(Shazly *et al.*, 2023).** According to **Abu-Heakal *et al.* (2016**), meals containing 2% flaxseed oil decreased saturated fatty acids in the milk of lactating cows and buffaloes while boosting unsaturated fatty acids and omega-3 fatty acids. Omega-3 fatty acids were more prevalent in the meat and milk of animals given flax. The omega-3 content of flaxseed enhances the metabolism of fatty acids, boosting the nutritional value of animal products and promoting the production of beneficial livestock products (**Maddock *et al.*, 2006; Cui *et al.*, 2022**). Cattle fed flaxseed had higher levels of the vital omega-3 fatty acid alpha-linolenic acid in their meat and milk (**Ward *et al.*, 2002**). More than thirty percent of the total protein content in these products comes from flaxseed meal, a wonderful source of high-quality protein for animal feed (**Petit *et al.*, 2001**).

Supplementing dairy cows' diets with flaxseed increased the production of ω-3 polyunsaturated fatty acids (n-3 PUFAs) in milk. The development of milk rich in n-3 PUFAs improves human health (**Hung *et al.*, 2022b**). Therefore, flaxseed is frequently fed to dairy cows to boost the amount of n-3 PUFA in their milk. To increase the amount of n-3 PUFA in milk, dairy cows were fed whole and ground flaxseed, flaxseed oil, and flaxseed meal **(Isenberg *et al.*, 2019).** Research shows that feeding flaxseed to dairy cows effectively increases the levels of omega-3 polyunsaturated fatty acids in milk. Cows fed extruded flaxseed have been shown to produce milk with higher levels of omega-3 polyunsaturated fatty acids (**Hung *et al.*, 2022a**).

Furthermore, the transition stage of dairy cows, from late gestation to lactation, has been the subject of considerable research. Dairy cows are facing the greatest hazard of metabolic and infectious diseases, or even mortality, at this time. A common source of fatty acids, flaxseed may help early- lactating cows with their negative energy balance. Dairy cows fed flaxseed throughout the transition phase had higher levels of antioxidant activity and post-calving liver glycogen, as well as lower levels of triglycerides, which may help prevent the formation of fatty liver (**Gandra *et al.*, 2016**). Early nursing calves may benefit from flaxseed by having a more favorable energy balance. Dairy cows that consumed flaxseed throughout the transition phase had lower triglyceride levels and higher increases in antioxidant activity and liver glycogen after calving (**Rajan *et al.*, 2023**). Incorporating flaxseed into the diets of dairy cows can improve their health by altering the fatty acid profile in their milk and reducing lipid buildup in the liver, consequently preventing the formation of fatty liver (**do Prado *et al.*, 2016**).

4. Reproductive traits

Most scientists have demonstrated that including flaxseed in the feed improves the herd's reproductive efficiency and increases early embryo survival **(Moats, 2015).** First-service conception rates were better in dairy cows given 17% flax (87.5 vs. 50.0%), and this response was ascribed to the cows' better energy balance **(Petit, 2003).** Holstein Friesian cows fed extruded flaxseed had faster ovulation and fewer cyclic follicles (**Zachut *et al.* 2010**). When whole, unprocessed flaxseed is fed to dairy cows, the omega-3 fatty acid content of fortified dairy products can be increased, which has been demonstrated to improve the quality of sperm collected after being frozen (**Gholami *et al.* 2010**). Because flaxseed oil increases the synthesis of sex hormones, it significantly increased the levels of the hormone estradiol-17β in sheep that were given flaxseed oil orally **(Nowak and Jeziorek, 2023).** Flaxseeds or flaxseed oil can enhance animal performance, especially in hot weather **(Habeeb *et al.*, 2023).** Due to increased energy and steroid hormone levels (progesterone/estrogen), flaxseed is linked to enhanced reproductive results in female animals (**Rajan *et al.*, 2023**). Male rabbit fertility was increased by flaxseed oil's omega-3 fatty acids, which also decreased abnormalities and increased sperm concentration, motility, proliferative activity, and viability (**Abu-Heakal *et al.*, 2016**).

Highlights

1. Due to its relatively high protein level (22.8%) and high oil content (35%), flaxseed is regarded as a source of both fat and protein. Flaxseed protein contains high concentrations of vital amino acids, a wealth of vital minerals, and several vitamins.
2. The greatest plant source of omega-3 fatty acids is flaxseed, which has a high content of polyunsaturated fatty acids (73%), a moderate quantity of monounsaturated fatty acids (18%), and a low content of saturated fatty acids (9%).
3. Seeds of flax are better when crushed before being added to the animal feed. Whole flaxseeds provide higher fiber content, while ground flax allows better nutrient absorption.

4. Flaxseed oil is the oil that is derived from flaxseed using an industrial process. Cattle are fed flax meal, a by-product of oil extraction from seeds, as an added source of protein.
5. Omega-3 fatty acids, a healthy unsaturated fat with several therapeutic applications, make up between 35% and 50% of the oil in flaxseed seeds. Because flaxseed oil contains a lot of α-linolenic acid, it has an outstanding n-6: n-3 fatty acid ratio of around 0.3:1.

CONCLUSION

The study indicates that incorporating flaxseeds byproduct into the feed of ruminant animals can enhance productivity and increase cost-effectiveness. The incorporating flaxseed into the diet enhances early embryo survival and boosts the reproductive capabilities of the herd. It is recommended to use a maximum of 5% flaxseed in cattle concentrate feed, 7.5% flaxseed meal (FSM) in calf diets, and 20% flaxseed in yearling feed for the sake of animal safety.

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