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Extraction, Health benefits and products of Flaxseed oil

Dampuri Laxmi Prasanna[1], Dr. Neha Thomas[2] and Dr. Abhinav Dayal[2]

[1]M.Sc Scholar, and [2]Assistant Professor,

Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, Uttarpradesh

**Corresponding Author: dampuriprasanna@gmail.com*

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ABSTRACT

Flaxseed oil, derived from the seeds of the flax plant *(Linum usitatissimum),* is a rich source of essential fatty acids, particularly alpha-linolenic acid (ALA), a type of omega-3 fatty acid. The extraction of flaxseed oil can be accomplished through several methods, including cold pressing, solvent extraction, and supercritical CO2 extraction, with cold pressing being the most common method due to its ability to preserve the oil's nutritional quality. Flaxseed oil is associated with numerous health benefits. It has been shown to improve cardiovascular health by reducing blood pressure, lowering cholesterol levels, and decreasing inflammation. The anti-inflammatory properties of flaxseed oil also contribute to improved joint health and reduced symptoms of arthritis. Additionally, its high content of ALA supports brain health and may help in the prevention of neurodegenerative diseases. Flaxseed oil is also beneficial for skin health, promoting hydration and reducing the symptoms of conditions such as eczema and dermatitis. In terms of products, flaxseed oil is available in various forms including liquid oil, softgel capsules, and as an ingredient in dietary supplements. It is also used in the food industry as a cooking oil, in salad dressings, and as a component in fortified foods. Moreover, flaxseed oil finds applications in the cosmetic industry, where it is incorporated into skin and hair care products due to its emollient and moisturizing properties. The versatility and health benefits of flaxseed oil make it a valuable addition to both dietary and personal care regimens.

Key words: *Linum usitatissimum,* Flaxseed oil, Alpha-linolenic acid, Extraction, Cold pressing

INTRODUCTION

Linseed *(Linum usitatissimum)* belongs to the family linaceae. It is a annual and self-pollinated diploid crop species (2n=2x=30). It is a dual purpose crop either it is grown for oil or fibre. Flaxseed, also known as linseed holds a rich historical 0significance as one of the oldest oil crops, with its Latin meaning "very useful" reflecting its versatile nature. Its cultivation spans across more than 50 countries globally, predominantly in the northern hemisphere. Flaxseed producing regions include Canada, mainland China, the United States, India, and Ethiopia. Canada and mainland China emerge

as the leading exporters in the flaxseed market, collectively contributing over 30% of global flaxseed trades, as per data from the Food and Agriculture Organization (FAO) in 2020. This highlights their significant roles in supplying this valuable commodity to various parts of the world.

Flaxseed is a powerhouse of bioactive compounds with numerous potential health benefits. Its components like alpha-linolenic acid (ALA), lignans, proteins, mucilage, minerals, and phenolic compounds contribute to its therapeutic properties. (Bechlin *et al.,* 2019; Giarola *et al.,* 2019; and Lan *et al.,* 2020). These benefits include reducing the risk of heart diseases and osteoporosis, exhibiting anti-tumor activities in mammary or prostate glands, acting as a laxative, displaying anti-inflammatory properties, and alleviating menopausal symptoms. Afzal *et al.,* 2020; DeLuca *et al.,* 2018; Parikh *et al.,* 2019; and Soltanian and Janhorbani 2018).

Flaxseed is a rich source of phytoestrogens, primarily in the form of lignans, Kajla *et al.,* 2015). Additionally, it boasts a significant presence of phenolic substances, with phenolic acid compounds, lignans, and flavonoid compounds being the main types, contributing to its antioxidant properties. Regarding minerals, flaxseed is notably abundant in magnesium, phosphorus, calcium, iron, copper, and zinc, Tuncel *et al.,* 2017). These minerals play essential roles in various bodily functions, including bone health, enzyme activation, and immune system support. The presence of anti-nutritional compounds like cyanogenic glycosides in flaxseed, including linamarin, linustatin, lotasutralin, and neolinustatin, Zhao *et al.,* (2019). These compounds can limit the utilization of flaxseed in food products due to their potential health risks. The presence of cyanogenic glycosides, various methods have been explored, such as enzymatic treatment, germination, boiling, mechanical treatment, and solvent extraction, as Bekhit *et al.,* 2018 and Li *et al.,* 2019). These methods aim to reduce the levels of cyanogenic glycosides to enhance the safety and usability of flaxseed in the food industry.

Flaxseed contain high content of alpha-linolenic acid (ALA), a type of omega-3 fatty acid. The oil extracted from flaxseed typically contains between 48% and 62% ALA Bakowska-Barczak *et al.,* 2020; Goyal *et al.,* 2018; and Moghadam *et al.,* 2019). This makes flaxseed oil one of the richest sources of ALA. In flaxseed itself, the ALA content can vary depending on factors such as cultivar and growing conditions. Levels of ALA in investigated flaxseed cultivars have been reported to range from 45.5% to 55.8% Abbasi *et al.,* 2019; Lan *et al.,* 2020; and Li *et al.,* 2020). Among the investigated cultivars, flaxseed oil consistently showed higher ALA contents compared to the seeds themselves. This high ALA content makes flaxseed and its oil valuable dietary components, especially for individuals seeking to increase their intake of omega-3 fatty acids, which are associated with various health benefits, including cardiovascular health and inflammation reduction.

Flaxseed oil composition

Flaxseed oil is primarily composed of fatty acids, with linolenic acid being the most abundant. Additionally, it contains various other compounds such as volatile compounds, phenolic compounds, tocopherol, and phytosterols. The specific composition of flaxseed oil includes approximately 96% triacylglycerides (TAG) and 1.4% polar lipids, glyco, and phospholipids. Dunford, 2015). The main TAG in flaxseed oil is trilinolenate (35%) Hall *et al.,* 2006). fatty acids of flaxseed oils were mainly composed of linolenic acid (53.36–65.84%), linoleic acid (10.14–16.39%), oleic acid (10.03–12.37%), stearic acid (3.98–9.85%) and palmitic acid (2.41–7.97%) Zhang *et al.,* 2017).

Fatty acids	Whole flaxseed (%)			Flaxseed oil (%)	
Palmitic acid	5.96–7.18[a]	5.76–6.63[b]	5.67–6.34[c]	5.13[d]	4.66[e]
Stearic acid	4.38–5.33[a]	4.13–5.63[b]	4.28–6.35[c]	3.38[d]	4.43[e]
Oleic acid	18.51–31.19[a]	26.38–31.38[b]	22.41–31.13[c]	19.3[d]	18.5[e]
Linoleic acid	12.03–16.52[a]	13.85–14.91[b]	12.45–15.37[c]	14.0[d]	14.5[e]
Linolenic acid	42.67–58.51[a]	43.54–48.35[b]	45.09–51.09[c]	55.4[d]	55.8[e]

*Deng *et al.* (2017); Zou *et al.* (2017).
*[a] Flaxseed from Inner Mongolia (seven cultivars): Huanghuma, Longya9, 75–11–5, Lunxuan3, Lunxuan2, Neiya6, Neiya9; [b]Flaxseed from Shanxi (five cultivars): Jinya7, Jinya9, Jinya10, Jinya11, Jinya12; [c]Flaxseed from Hebei (six cultivars): Baya9 (12), Baya9(13), Baya11, Baya12(12), Baya12(13), Baya11(11); [d]Flaxseed cultivar Dingya23; [e]Flaxseed cultivar Zhongya1.

Extraction of Flaxseed Oil

The extraction of flaxseed oil typically involves mechanical pressing or solvent extraction Sharma *et al.,* 2019; and Shim *et al.,* 2015). Mechanical pressing involves pressing the flaxseeds to extract the oil, while solvent extraction uses solvents to dissolve the oil from the seeds. Freshly pressed flaxseed oil often retains a nutty flavor and varies in color from yellow to orange, reflecting its natural properties. To enhance its quality and prolong shelf life, flaxseed oil commonly undergoes several purification steps, including settling, alkali refining, degumming, bleaching, winterization, and deodorization. These processes help remove impurities, improve clarity, and stabilize the oil. Various factors can influence the extraction process, including the pretreatment of flaxseeds, moisture content, different flaxseed cultivars, pressing conditions, and more Dunford 2015). These factors play a crucial role in determining the quality and yield of the extracted oil.

The dehulling process for flaxseed

Dehulling plays a significant role in enhancing the extraction of oil from oilseeds, particularly in the case of flaxseed, where the hulls contain mucilage and crude fiber Kaushik *et al.,* 2016). Various dehulling methods, including dry mechanical, wet (assisted by mechanical means), and sprouting processes, have been developed to facilitate oil extraction Lan *et al.,* 2020; Lv and Huang, 2015). Wet processes with mechanical stirring are effective in removing mucilage, especially when higher extraction temperatures are employed compared to cold water extraction (Kajla *et al.,* 2015). However, wet extraction processes have complex operational requirements and may not be ideal for removing flaxseed hulls (Sharma *et al.,* 2019; Piva *et al.,* 2017), necessitating alternative dehulling methods.

Dry dehulling processes have been proposed for many years, with significant advancements made recently, particularly in China, where industrial applications began in 2017 (Shim *et al.,* 2015). Factors such as seed moisture content, pretreatment methods, and dehulling time significantly influence dehulling efficiency. Recent studies have explored innovative pretreatment techniques, such as acidic moisture conditioning combined with low-temperature drying, to enhance flaxseed oil extraction (Zhang *et al.,* 2020). For example, pretreatment with 0.30 M citric acid followed by drying at 70°C for 1 hour resulted in an 83.27% oil recovery rate. Reducing moisture content also improves the temperatures of both flaxseed oil and meals (Zheng *et al.,* 2005). A decrease in moisture content from above 7.5% to 6.1% can significantly increase the temperature of expressed oil from 49–50°C to 67°C. Furthermore, there is an inverse correlation between flaxseed moisture content and oil

yield, with oil yield substantially increasing as moisture content decreases from 13.8% to 6.5% (Singh *et al.,* 2011).

Mechanical pressing for extracting flaxseed oil

The method chosen for extracting flaxseed oil significantly impacts its quality and nutritional content. Cold pressing is often preferred for preserving high levels of alpha-linolenic acid (ALA), a beneficial omega-3 fatty acid. However, it comes with drawbacks such as incomplete microbial elimination and lower levels of certain beneficial compounds like vitamins, phospholipids, phytosterols, and antioxidants (Tanska *et al.,* 2018). To maintain the quality of flaxseed oil, it's recommended to store it in dark containers and incorporate antioxidants.

To overcome the limitations of cold pressing, alternative methods have been explored. These include using more aggressive conditions, heating, or enzyme treatments prior to pressing (Dunford, 2015). Enzyme-assisted cold pressing has shown promise in enhancing oil yield and improving oxidative stability compared to traditional cold pressing methods (Anwar *et al.,* 2013). By breaking down cell walls and facilitating oil extraction, enzyme treatments can lead to oils with higher ALA levels and improved quality. Additionally, employing multiple pressing steps or enzyme treatments can further optimize the extraction process, resulting in oils with enhanced nutritional profiles and improved overall quality. While cold pressing is favored for preserving ALA content, exploring alternative extraction methods offers opportunities to enhance both yield and quality of flaxseed oil. Ultimately, the choice of extraction method depends on balancing the preservation of key nutrients with considerations of efficiency and quality.

New extraction methods for flaxseed oil

various extraction methods for flaxseed oil, each with its own set of advantages and potential improvements over traditional mechanical pressing.

1)Three-Phase Partitioning: This method involves adding salt and t-butanol to aqueous extracts to extract flaxseed oil. (Kulkarni *et al.,* 2017; Sharma *et al.,* 2019). Studies have shown promising results, with enzyme-assisted three-phase partitioning yielding up to 71.68% oil under optimized conditions. (Tan *et al.,* 2016).

2) Supercritical Carbon Dioxide (SC-CO2) Extraction: SC-CO2 extraction is effective for extracting heat-sensitive and fat-soluble compounds. (Dabrowski *et al.,* 2019; Sharma *et al.,* 2019). It has been reported to yield around 30.03% of flaxseed oil with excellent quality (Kulkarni *et al.,* 2017). Parameters such as flow rate, temperature, and extraction time significantly influence oil recovery, with reported recoveries ranging from 28.7% to 92.3%.

3) Subcritical Fluid Extraction: Using subcritical propane has shown advantages in terms of solvent use and yield. Flaxseed oil obtained through this method often exhibits better quality compared to mechanically extracted oil. (Piva *et al.,* 2018).

4) Accelerated Solvent Extraction (ASE): ASE employs organic or aqueous solvents at improved temperatures and pressures to extract flaxseed oil. It has shown comparable yields to conventional solvent extraction and higher yields than SC-CO2 extraction. (Khattab and Zeitoun 2013).

5) Ultrasound-Assisted Extraction: This method uses ultrasound power as an assistant tool, resulting in less solvent usage and faster extraction. (Dunford, 2015; Sharma *et al.,* 2019). Studies have reported high recovery rates, reaching up to 84.9%. (Zhang *et al.,* 2008).

6) Microwave-Assisted Extraction: Microwave pre-treatment of flaxseeds has emerged as an alternative to conventional pressing methods. It offers advantages such as shorter processing time, lower solvent usage, and higher yield. (Fathi-Achachlouei *et al.,* 2019). Microwave treatment has been shown to improve oil yield, oxidative stability, and antioxidant activity of flaxseed oils. (Suri *et al.,* 2020). Each method presents its own set of advantages and considerations, allowing for flexibility and optimization based on specific extraction needs and desired oil quality.

Health Promoting Benefits of Flaxseed oil

Flaxseed oil in atherosclerosis treatment

Atherosclerosis is indeed a complex condition characterized by the buildup of fats, cholesterol, and other substances in and on the walls of arteries. It's often referred to as a "hardening" or "narrowing" of the arteries due to the formation of plaque. The factors you mentioned play crucial roles in its development:

Interleukin 1-beta (IL-1β): This is a pro-inflammatory cytokine that promotes inflammation, which can contribute to the initiation and progression of atherosclerosis.

Hypercholesterolemia: High levels of cholesterol in the blood, particularly low-density lipoprotein (LDL) cholesterol, are strongly associated with the development of atherosclerosis. LDL cholesterol can infiltrate the arterial walls and trigger an inflammatory response, leading to plaque formation.

Tumor Necrosis Factor (TNF): Another pro-inflammatory cytokine, TNF, is involved in various processes related to atherosclerosis, including inflammation, endothelial dysfunction, and plaque instability.

Eicosanoids: These are signaling molecules derived from fatty acids, which can modulate inflammation, blood clotting, and vascular tone. Certain eicosanoids have been implicated in the pathogenesis of atherosclerosis.

Cytokines: In addition to IL-1β and TNF, various other cytokines produced by immune cells and other cell types contribute to the inflammatory processes underlying atherosclerosis.

Platelet-Activating Factor (PAF): PAF is a lipid mediator involved in platelet activation and inflammation. It can promote endothelial dysfunction and vascular inflammation, which are key features of atherosclerosis.

Reactive Oxygen Species (ROS): ROS are more reactive molecules that can cause oxidative damage to cells and tissues. Oxidative stress plays a critical role in the development and progression of atherosclerosis by promoting inflammation, endothelial dysfunction, and lipid oxidation.

This study suggests that substituting lard with flaxseed oil in the diet can alleviate symptoms of atherosclerosis, improve oxidative stress levels, and reduce abnormalities in lipid metabolism and inflammation. This indicates the potential of flaxseed oil as a dietary therapy for managing atherosclerosis. (Han *et al.,* 2018). This research demonstrates that ALA, found in high levels in

flaxseed oil, has anti-inflammatory properties. Specifically, it reduces inflammatory responses in endothelial cells, which are crucial in the development and progression of atherosclerosis. (Shen *et al.,* 2018). Their findings suggest that dietary flaxseed oil possesses protective activity against cardiac toxicity induced by arsenic exposure. Flaxseed oil was shown to decrease arsenic accumulation and prevent structural alterations in the heart, indicating its potential role in preventing cardiovascular damage. (Varghese *et al.,* 2017).

Overall, these studies provide evidence supporting the beneficial effects of flaxseed oil, particularly its ALA content, in combating various aspects of atherosclerosis and related cardiovascular conditions. Incorporating flaxseed oil into the diet may offer a natural and potentially effective approach to managing and preventing the progression of atherosclerosis. However, further research, including clinical trials, is necessary to fully understand its mechanisms of action and optimal use in clinical settings.

Flaxseed oil in kidney diseases

The kidney's role in filtering out toxins and waste products is indeed crucial for maintaining overall health, particularly as we age. Renal dysfunction can pose serious health risks, necessitating advanced treatments like dialysis or transplantation. The potential benefits of dietary flaxseed oil in mitigating renal toxicity induced by thioacetamide in male rats were explored. The findings suggested that administering flaxseed oil could help protect against biochemical and histopathological changes induced by thioacetamide. This protective effect was attributed to the antioxidant properties inherent in flaxseed oil. (Omar 2018). Similarly, flaxseed oil supplementation could significantly reduce the expression levels of pro-inflammatory cytokines such as interleukin (IL)-6 and IL-1β in the kidney compared to control groups. This reduction in inflammation was proposed to contribute to the amelioration of renal injury induced by cisplatin, highlighting the anti-inflammatory potential of alpha-linolenic acid (ALA) present in flaxseed oil. (Kheira *et al.,* 2019).

These studies underscore the potential therapeutic value of flaxseed oil in protecting against renal damage and inflammation, offering insights into potential dietary interventions for renal health management.

Flaxseed oil in brain health

Flaxseed oil, rich in omega-3 polyunsaturated fatty acids, may have beneficial effects on brain health. Increased expression levels of brain-specific proteins associated with neuronal function and structure in young mice fed diets supplemented with flaxseed oil during maternal pregnancy and lactation. (Tian *et al.,* 2011). This indicates a potential role for flaxseed oil in supporting brain development during crucial early stages. Moreover, found evidence of neuroprotective effects of flaxseed oil in rats' brains subjected to gamma-irradiation or carbon tetrachloride-induced damage. (Ismail *et al.,* 2016). This suggests that flaxseed oil may help mitigate the harmful effects of certain toxins or radiation on brain tissue. Both studies suggest that the optimal ratio of omega-6 to omega-3 fatty acids, particularly in the range of 1-2:1, may be important for maximizing the neurological benefits of flaxseed oil. This balance is thought to be crucial for maintaining proper brain function and protecting against neurodegenerative processes. However, it's essential to interpret these

findings within the context of broader research and consult with healthcare professionals before making significant dietary changes or using flaxseed oil as a therapeutic intervention for brain health.

Flaxseed oil in obesity

The potential benefits of incorporating flaxseed oil into the diet as a means to combat obesity and its associated health risks. Supplementation with either flaxseed oil or sunflower seed oil led to significant reductions in weight among patients. Additionally, flaxseed oil supplementation was specifically associated with decreased waist circumference, which is a significant marker of abdominal obesity and a risk factor for various chronic diseases. (Akrami *et al,.* 2018). A medium dose of flaxseed oil had a positive impact on inhibiting the metabolic activation of adipose tissue macrophages. This inhibition can potentially lead to improved insulin signaling within tissues, which is crucial for glucose metabolism and may help in the management of conditions like type II diabetes. (Yu *et al.,* 2017). These findings suggest that incorporating flaxseed oil into the diet may offer a multifaceted approach to combat obesity and its related metabolic complications. However, as with any dietary intervention, it's important to consider individual factors and consult with healthcare professionals to ensure safe and effective implementation, especially for individuals with pre-existing health conditions.

Flaxseed oil in cardiovascular diseases

Flaxseed oil indeed offers promising potential in reducing the risk of cardiovascular diseases, including cardiac arrhythmia. Its beneficial effects on hypertensive and hyperlipidemic patients are well-documented, primarily due to its high content of alpha-linolenic acid (ALA). ALA is an omega-3 fatty acid known for its hypocholesterolemic properties and its ability to improve lipid profiles. The cardiovascular benefits of flaxseed oil consumption, further studies are necessary to fully elucidate the mechanisms behind its antihypertensive effects. Nonetheless, incorporating flaxseed oil into one's diet appears to be a practical strategy for reducing the risk of cardiovascular disease based on the reported data. It's essential to acknowledge that individual responses to dietary interventions can vary, and consulting with a healthcare professional before making significant dietary changes is always advisable, especially for individuals with pre-existing medical conditions or those taking medications. implementation, especially for individuals with pre-existing health conditions.

Flaxseed oil in skeletal muscle and bone health

The research findings you've presented highlight the multifaceted benefits of consuming flaxseed oil, particularly its positive impact on skeletal muscle lipid composition and bone health.

1. Skeletal Muscle Benefits: Flaxseed oil, rich in alpha-linolenic acid (ALA), enhances the movement of lipids across the sarcolemmal membrane, thus facilitating fatty acid oxidation. Rats fed with a diet supplemented with ALA exhibited increased omega-3 polyunsaturated fatty acids (PUFAs) in muscle and sarcolemmal membranes, leading to elevated rates of palmitate transport and whole-body fat oxidation. Additionally, skeletal muscle triacylglycerol content increased significantly. These effects collectively suggest that flaxseed oil consumption can enhance skeletal muscle lipid metabolism and fat utilization.

2. Bone Health: Flaxseed oil's benefits extend to bone health as well. Diets rich in PUFA, such as those containing flaxseed oil, have been associated with improvements in femur bone mineral density, bone strength, and fatty acid composition. Rats fed high n-3 PUFA diets showed stronger femurs compared to those on a standard diet. Furthermore, flaxseed oil supplementation has been found to ameliorate trabecular bone damage induced by high-fat diets and promote osteoblastic function and osteogenesis. Consumption of flaxseed oil has also been shown to improve bone microarchitecture compared to other sources of n-3 PUFAs. Overall, flaxseed oil consumption appears to promote skeletal muscle lipid composition and bone health through various mechanisms, including enhanced fatty acid oxidation, improved bone mineral density and strength, and mitigation of bone damage. While further studies are needed to compare the efficacy of flaxseed oil with other omega-3 rich oils, its potential to enhance osteogenesis and overall bone health is promising.

Other health benefits

Flaxseed oil exhibits notable protective effects against gastric ulcers induced by ethanol in rats. Oral pre-treatment with flaxseed oil resulted in a significant reduction in both the number and length of ulcers compared to control animals treated with an equivalent amount of corn oil. Interestingly, flaxseed oil at a dose of 5.0 ml/kg showed greater efficacy than ranitidine, a commonly used medication for gastric ulcers. This suggests that flaxseed oil could be a promising adjunct therapy to conventional treatments, potentially reducing the need for higher doses of antacids or mitigating their side effects when used over an extended period. Moreover, flaxseed oil has been recognized for its therapeutic effects on dry eye syndrome. Oral supplementation with flaxseed oil capsules, at doses of 1 or 2 g/day, has been shown to reduce ocular surface inflammation and improve symptoms of keratoconjunctivitis sicca in patients with Sjögren's syndrome. Additionally, the development of a nano-emulsion artificial tear containing flaxseed oil has demonstrated significant improvements in ocular staining when compared to commercial artificial tears lacking flaxseed oil. This innovative formulation shows promise in addressing various aspects of ocular health, including corneal and conjunctival staining, suggesting a potential role for flaxseed oil in ocular surface health and management of dry eye syndrome. It understands the diverse therapeutic potential of flaxseed oil, not only in gastrointestinal health but also in addressing ocular surface disorders. Further research may elucidate its mechanisms of action and optimize its use in clinical settings.

Flaxseed Oil-Based Products

Flaxseed's versatility in culinary applications and its nutritional benefits, particularly its high ALA content, have made it a popular choice in dietary supplements and food products. (Bekhit *et al.,* 2018; Mohseni and Goli, 2019). However, the sensitivity of flaxseed oil to external factors like oxygen, light, and high temperatures presents challenges in its storage and use, as it can lead to rancidity and decreased sensory quality. (Bekhit *et al.,* 2018; Mohseni and Goli, 2019). Consequently, proper storage in dark bottles is recommended. Despite these challenges, there has been significant research and development in incorporating flaxseed oil into various foods, ranging from baked goods to beverages and meat products. (Baba *et al.,* 2018; Bolger *et al.,* 2018; Farbod *et al.,* 2015; Gowda *et al.,* 2018; Goyal *et al.,* 2016; Kumar *et al.,* 2017; Reddy *et al.,* 2016; Ramel *et al.,* 2017; Osuna *et al.,* 2018; Veena *et al.,* 2017). Laboratory-scale studies have explored its potential applications, and products such as flaxseed oil soft capsules have been introduced as

functional food supplements in markets like China. Additionally, innovative flaxseed oil-based products, including instant powder, yogurt, and baked goods, have been developed and made available commercially. This indicates a growing interest in utilizing flaxseed oil beyond traditional supplement forms, extending its reach into a wider range of food products, potentially offering consumers more convenient and diverse options to incorporate its nutritional benefits into their diets.

In food products

Oil, including breads, cookies, drinks, ice cream, salad dressings, sausages, egg sticks, yogurts, fat spreads, surimi, cheese, and more, have been documented in research (Manshadi *et al.,* 2019; Ramel and Marangoni, 2017). This diverse range of food items demonstrates the adaptability of flaxseed oil in various culinary applications, offering consumers a wide array of choices to incorporate its nutritional benefits into their diets.

Bakery products

The potential utilization of flaxseed oil in bakery products. (Osuna *et al.,* 2018). While many of these studies have been conducted at the laboratory scale, they suggest that bakery products could be particularly suitable for incorporating flaxseed oil due to their widespread consumption. Focused on cookies supplemented with flaxseed oil at varying replacement ratios. Their findings revealed improvements in several physical properties of the cookies, such as weight, diameter, thickness, spread ratio, and breaking strength, with increasing flaxseed oil replacement (Rangrej *et al.,* 2015). However, it was noted that the acceptable quality of cookies was compromised when the replacement ratio exceeded 30% of the shortening. This suggests that while flaxseed oil can enhance certain characteristics of bakery products, careful consideration of the replacement ratio is essential to maintain overall product quality and consumer acceptability.

Ice cream

Ice cream may be an ideal food system for incorporating flaxseed oil due to its low storage temperature (-18 oC). Prepared ice cream incorporated with flaxseed oil powder, and revealed that ALA con tent in fortified ice cream deceased 18.74–21.38% after 120 days of storage (Gowda *et al.,* 2018). The author concluded that flaxseed oil powder could be incorporated into ice cream at 4.0% level.

Meat products

The addition of flaxseed oil to chicken sausages could alter the physical properties of the sausage matrix, with encapsulated flaxseed oil having a more significant impact compared to other forms. This suggests that the form of flaxseed oil used in food products can influence their physical characteristics. (Bolger *et al.,* 2018). The potential of incorporating rice bran oil and flaxseed oil into designer chicken shred, which resulted in a product with good overall acceptability, indicating that flaxseed oil can be utilized alongside other oils to create healthier chicken-based foods. (Reddy *et al.,* 2016). Fortifying liver pate with flaxseed oil and flaxseed extract led to a significant reduction in saturated and monoenoic fatty acids and an increase in phytosterol content, suggesting that flaxseed oil can be used to improve the nutritional profile of meat products (Bilska *et al.,* 2018). Fortified

Alaska pollock surimi seafood with a blend of ω-3 oils, including flaxseed, algae, and menhaden oils, resulting in improved rheological and textural properties of the surimi (Debusca *et al.,* 2013). The addition of a blend of ω-3 oils, including flaxseed oil, algae oil, menhaden oil, and krill oil, did not significantly influence the texture properties of surimi seafood. This suggests that the impact of flaxseed oil and other ω-3 oils on the texture of surimi may vary depending on the specific formulation and processing conditions. (Pietrowski *et al.,* 2011, 2012). Overall, these studies highlight the potential of flaxseed oil as a functional ingredient in a variety of food products, from sausages to seafood, offering both nutritional benefits and potential improvements in product quality.

Milk and milk products

Milk and milk products, owing to their high consumption frequency and low storage temperature, present favorable conditions for fortification with flaxseed oil. Bermudez-Agurirre and Barbosa-Canova (2011) incorporated flaxseed oil into various cheeses, including queso fresco, cheddar, and mozzarella, demonstrating good storage stability for the fortified cheese under refrigerated conditions, with a storage life of approximately 16 days. Fortified Indian yogurt (dahi) with flaxseed oil powder, observing higher acidity in the fortified dahi compared to the control after 12 days of storage. Despite a reduction in ALA content by approximately 21% after 15 days of storage, the fortified dahi maintained acceptable quality. (Goyal *et al.,* 2016). Fortified dahi with flaxseed oil, phytosterols, and polydextrose, noting no significant impact on pH, acidity, or mouthfeel. The fortified dahi exhibited chemical stability and contained notable amounts of ALA, phytosterols, and polydextrose. (Veena *et al.,* 2017). In the case of yogurt fortified with flaxseed and walnut oils using guar gum as a stabilizer, improved syneresis and antioxidant properties were observed, though the viable count in yogurt decreased compared to the control. Sensory evaluation favored walnut oil-fortified yogurt over flaxseed oil-fortified yogurt. (Baba *et al.,* 2018). Prepared fruit yogurt incorporating flaxseed oil, flaxseed flour, and fruits, finding that the sensory properties of yogurt were significantly influenced by the addition amounts of flaxseed. Optimal sensory attributes were achieved with a maximum addition of 2.0% flaxseed oil, resulting in fruit yogurt with a high ALA content of up to 22.80%. (Kumar *et al.,* 2017b) These studies collectively suggest the feasibility and potential benefits of fortifying milk and milk products with flaxseed oil, offering consumers additional nutritional value without compromising product quality.

CONCLUSION

It's clear that while significant progress has been made in utilizing flaxseed oil and understanding its potential health benefits, there are still areas where further research and development are needed.

1) Consumer Awareness and Education: Enhancing public understanding of the health advantages associated with flaxseed oil is crucial. Education campaigns can help consumers make informed choices about incorporating flaxseed oil into their diets, potentially increasing its demand and consumption.
2) Development of High-Value Products: Expanding the range of high-value flaxseed oil-based products could open up new markets and opportunities. Investing in research and innovation

to create innovative and appealing products could drive consumer interest and benefit the industry as a whole.

3) Improving Stability: The poor stability of ALA in flaxseed oil poses a significant challenge for its application in the food industry. Exploring advanced techniques such as nano-emulsion production, microwave technology, high-power ultrasound, and spray drying could help enhance the stability of flaxseed oil and extend its shelf life, thus broadening its potential applications.

4) Understanding Mechanisms and Health Benefits: While there is evidence supporting the health-promoting properties of flaxseed oil, further studies are needed to fully elucidate the mechanisms behind its effects on disease treatment and prevention. This research could provide valuable insights into its therapeutic potential and guide the development of targeted interventions.

5) Enriched Animal Products: Investigating the production of ALA-enriched animal products through feeding animals a diet supplemented with flaxseed oil offers another avenue for expanding the utilization of flaxseed oil. This approach could not only enhance the nutritional profile of animal products but also provide consumers with an additional source of beneficial fatty acids. Addressing these challenges and opportunities through continued research, innovation, and education efforts will be essential for maximizing the potential of flaxseed oil in promoting health and well-being.

Breeding perspetives

Breeding flaxseed plants for oil extraction involves selecting varieties with high oil content and quality, as well as traits like disease resistance and yield. Health benefits of flaxseed oil include omega-3 fatty acids that support heart health, anti-inflammatory properties, and potential benefits for skin and hair. Products derived from flaxseed oil include dietary supplements, cosmetics, and culinary oils, all contributing to its popularity in both health and industrial applications.

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