

Flaxseed as a Functional Superfood: Advances in Nutritional Insights, Bioactive Components, Health Benefits, and Innovative Applications

RUCHIKA¹, DR. MANSHI²

^{1, 2}Swami Vivekanand Subharti University, Meerut

Abstract- Flaxseed (*Linum usitatissimum*) is a nutrient-rich superfood that has been used for centuries for its health and nutritional benefits. It is high in bioactive compounds, including alpha-linolenic acid (ALA), lignans, dietary fibre, and plant-based protein, which support heart health, metabolism, hormone balance, and provide antioxidant and anticancer benefits. Regular consumption of flaxseed has been shown to improve blood lipid levels, blood sugar control, reduce inflammation, and support digestive health. Flaxseed is especially beneficial for women with polycystic ovary syndrome (PCOS), as ALA and lignans can help regulate hormones, improve insulin sensitivity, and support healthy lipid metabolism. Flaxseed can be easily added to the diet through foods like bread, cookies, smoothies, salads, and supplements, boosting their nutritional value by adding fibre, protein, omega-3 fats, and antioxidants. Its by-products, such as defatted flaxseed cake and mucilage, also have uses in industry, agriculture, and environmental applications, promoting sustainability. Looking ahead, functional foods and nutraceuticals can be developed to target general health and specific conditions like PCOS, diabetes, and obesity. Techniques such as microencapsulation or combining flaxseed with probiotics may improve the stability and absorption of its bioactive compounds. However, more long-term studies are needed to determine the best dose, form, and duration of flaxseed intake for managing hormonal and metabolic issues. Overall, flaxseed is a safe, natural, and versatile way to improve nutrition, support hormone and metabolic health, and promote overall well-being.

I. INTRODUCTION

The flax plant, scientifically named *Linum usitatissimum*, produces seeds commonly called flaxseed or linseed (Kaur, 2023). Global flaxseed production in 2019 totalled 738,000 tonnes, of which around 60% came from China, the United States, and Belgium (Fan et al., 2023). Flaxseed is one of the oldest cultivated crops, valued historically for both its

fibre and oil. Archaeological and historical evidence indicates that flaxseed has been consumed for centuries due to its nutritional richness and medicinal properties, particularly in traditional systems of medicine across Asia and Europe (Tolkachev & Zhuchenko, 2000). The seeds yield an oil that is frequently employed for cooking (Singh et al., 2011). Due to its bioactive-rich composition, flaxseed is classified as a superfood, supporting cardiovascular health, blood sugar control, and providing antioxidant and anticancer benefits (Nowak & Jeziorek, 2023; Sabet et al., 2024). Flaxseed is a nutrient-dense seed, high in fat, protein, and dietary fiber. Its chemical composition typically includes 30–40% fat, 20–25% protein, 20–28% total dietary fiber, 4–8% moisture, and 3–4% ash, with the oil also providing vitamins A, B, D, E, minerals, and amino acids. Flaxseed is nutritionally rich, providing significant amounts of α -linolenic acid (ALA), an essential omega-3 fatty acid, along with dietary fiber (both soluble and insoluble), high-quality plant protein, and lignans—particularly secoisolariciresinol diglucoside (SDG), which possesses antioxidant and phytoestrogenic properties (Kajla et al., 2015; Goyal et al., 2014). These bioactive compounds have the potential to enhance metabolic function, support hormonal balance, and alleviate inflammation, which are central features of PCOS pathophysiology. In particular, the soluble and insoluble fiber in flaxseed may help improve glucose regulation and body weight control, while ALA and lignans have been reported to favourably influence lipid metabolism, inflammatory markers, and reproductive hormone levels (Haidari et al., 2020; Najdgholami et al., 2020). Evidence from experimental, clinical, and population-based studies suggests that consistent consumption of flaxseed and flaxseed-based products improves lipid metabolism, reduces inflammation, regulates glucose homeostasis,

and provides antioxidant protection (Pan et al., 2009; Parikh et al., 2019). Several clinical investigations have explored the impact of flaxseed supplementation in women with PCOS.

Moreover, flaxseed lignans are known to influence oestrogen metabolism and intestinal microbiota, leading to increased bioavailability and biological activity (Adolphe et al., 2010). Owing to its wide-ranging biological activities—such as improving lipid profiles, lowering blood pressure and blood glucose, and exerting antioxidant and anticancer effects—flaxseed is classified as a superfood, primarily because of its rich content of bioactive constituents (Nowak & Jeziorek, 2023; Sabet et al., 2024).

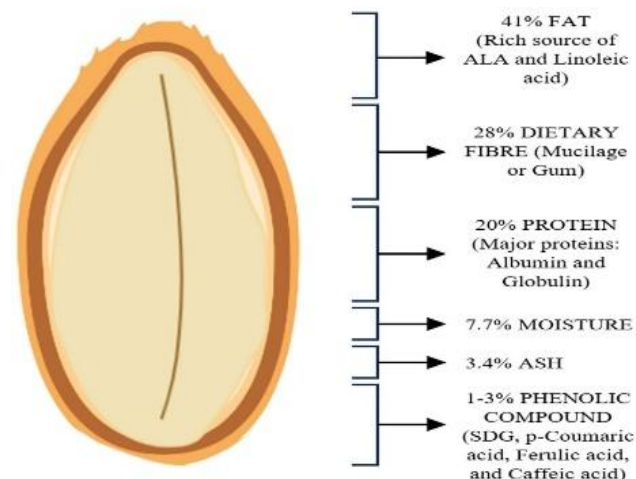


Flaxseed Composition

Flaxseeds typically measure about $2.5 \times 5.0 \times 1.5$ mm and vary in colour from yellow to black (Soni et al., 2016; Freeman, 1995). The flaxseed is oval, flat, and pointed at one end, with colour varying from yellow to dark brown. Its structural components include a true seed coat (testa), a delicate endosperm, two embryos, and an embryonal axis (Morris, 2007). The seed coat, or testa—also known as the envelope—contains roughly fifteen percent of the total mucilage present in the seed. It has been reported that flaxseed exhibits a negative relationship between its oil and protein content, with protein levels declining as oil content rises (Katare et al., 2012). Flaxseeds are commonly classified into yellow and golden-brown types, which show minimal differences in nutritional composition and contain similar amounts of short-chain omega-3 fatty acids (Amin & Thakur, 2014).

Flaxseed Nutritional Composition

Flaxseed is a nutrient-rich seed renowned for its high levels of polyunsaturated fatty acids (PUFAs), dietary fiber, proteins, vitamins, minerals, and bioactive constituents. Its compositional profile has made it a functional food of considerable interest, offering potential health benefits such as cardiovascular support, antioxidant properties, and regulation of blood glucose (Talwar et al., 2025).



Macronutrients

Lipids (Fats)

Flaxseeds are rich in oil, comprising roughly 35–45% of the seed's weight. The majority of this fat is polyunsaturated, with alpha-linolenic acid (ALA) accounting for more than 70% of the total fatty acids (Grundy et al., 2012). Saturated fats are relatively low, around 9–10%, while monounsaturated fats, mainly oleic acid, contribute about 15–20% (Talwar et al., 2025). Due to its high ALA content, flaxseed is considered one of the top plant-based sources of omega-3 fatty acids (European Journal of Medical Research, 2023).

Protein

Flaxseeds have about 20–30% protein. Most of this protein comes from globulins and albumins (Grundy et al., 2012). The protein contains most essential amino acids, but lysine is the one found in the lowest amount (Talwar et al., 2025).

Carbohydrates and Dietary Fiber

Flaxseeds have about 28% carbohydrates, with most of it being dietary fiber. They contain soluble fiber

(mucilage) and insoluble fiber (cellulose and lignin), which help with digestion, lowering cholesterol, and controlling blood sugar (Talwar et al., 2025).

Micronutrients and Bioactive Components

Lignans

Flaxseed is a very rich source of lignans, especially secoisolariciresinol diglucoside (SDG). These compounds have antioxidant effects and can act like plant-based oestrogens. The SDG content in flaxseed ranges from about 0.7% to 1.9% of its dry weight (Healthy Flax, 2024).

Vitamins and Minerals

Flaxseed contains important B vitamins, vitamin E (tocopherols), and minerals such as magnesium, phosphorus, potassium, calcium, iron, and zinc. The exact amounts can vary depending on the flaxseed variety and growing conditions (Food Research Journal, 2024; Talwar et al., 2025).

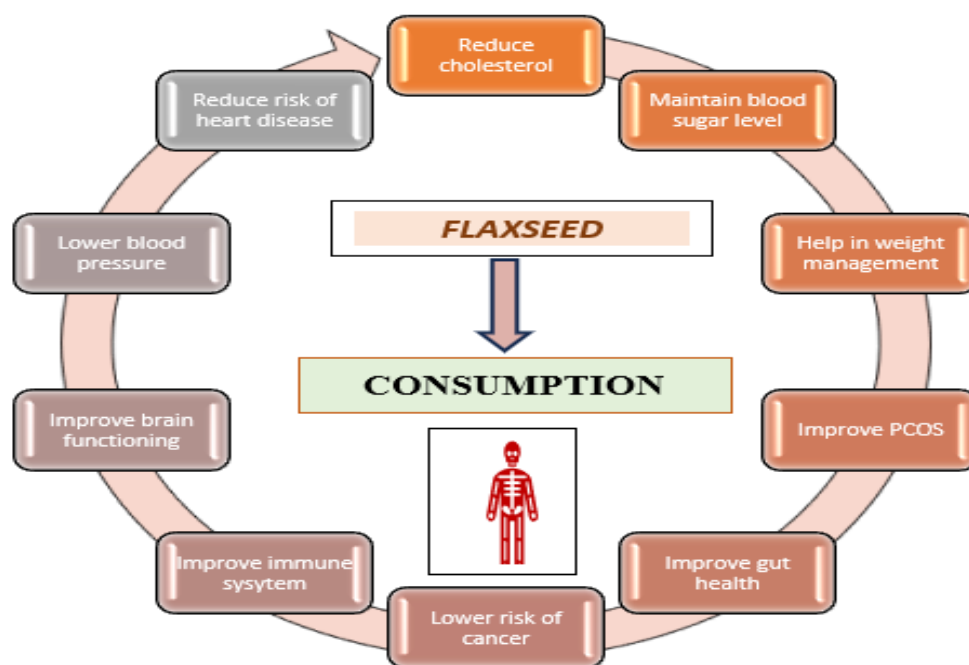
Other Bioactive Compounds

Flaxseed also has phenolic compounds and flavonoids, which provide additional antioxidant benefits and help make it a valuable functional food (Healthy Flax, 2024).

Flaxseed Nutrition Facts: Why This Ancient Grain Is a Modern Superfood

- Flaxseed contains about 40–42% oil, and around 50–55% of this oil is α -linolenic acid (ALA) (Nowak & Jeziorek, 2023). ALA is an important omega-3 fatty acid that helps reduce inflammation and supports heart health. Regular consumption of flaxseed has been linked to lower blood pressure, better cholesterol levels, and a reduced risk of cardiovascular disease (GeroScience Review, 2025).
- Flaxseed is a rich source of dietary fiber, making up about 28–40% of its total weight, and it contains both soluble and insoluble fiber (Ayelign & Alemu, 2016). The soluble fiber helps slow down sugar absorption and lowers cholesterol levels, while the insoluble fiber supports regular bowel movements and overall gut health (Nowak & Jeziorek, 2023).

- Flaxseed contains about 18–30% protein, with the amount varying according to the type of seed and growing conditions (Ayelign & Alemu, 2016). Its proteins are rich in amino acids such as arginine and glutamine, which support immune function, heart health, and blood circulation. Flaxseed is the highest known dietary source of lignans, especially secoisolariciresinol diglucoside (SDG), with levels between 610 and 1300 mg per 100 g. Flaxseed has magnesium and manganese support strong bones and healthy blood sugar levels, while selenium and zinc help the immune system and protect cells from damage. However, grinding, soaking, or cooking flaxseed reduces these compounds, making it safe to eat in normal amounts (Nowak & Jeziorek, 2023).
- In addition, flaxseed protein helps increase feelings of fullness and supports healthy metabolism. Flaxseed contains important vitamins, especially thiamine (vitamin B1), which helps the body produce energy and supports the nervous system. Flaxseed is rich in minerals such as magnesium, phosphorus, copper, manganese, iron, zinc, and selenium, which help the body with enzyme function and antioxidant protection (Healthline, 2024).
- In the digestive system, SDG is converted into enterolactone and enterodiol, which act as antioxidants and help regulate hormones and reduce inflammation (Nutrients, 2024). Eating flaxseed lignans has been linked to a lower risk of hormone-related cancers, such as breast and prostate cancer (PubMed Review, 2023).
- Flaxseed also has smaller amounts of vitamin B6 and folate, which are important for making red blood cells and maintaining overall metabolism. Flaxseed has small amounts of cyanogenic glycosides and phytic acid, which can lower mineral absorption if eaten in very large amounts (Ayelign & Alemu, 2016).
- These antioxidants may help prevent chronic diseases like heart disease, diabetes, and brain-related conditions (Nutrients, 2024).



Health Benefits of Flax Seeds

Impact of Flaxseed on Polycystic Ovary Syndrome (PCOS)

Polycystic ovary syndrome (PCOS) is a condition marked by hormonal imbalance, insulin resistance, and long-term inflammation. Studies suggest that flaxseed supplementation may help manage PCOS by improving insulin sensitivity, reducing body weight and waist circumference, improving lipid levels, and restoring the luteinizing hormone (LH) to follicle-stimulating hormone (FSH) ratio.

A randomized controlled trial reported that daily consumption of 30 g of flaxseed led to significant improvements in both hormonal and metabolic parameters in women with PCOS (Jamilian et al., 2020). Additionally, flaxseed lignans may help lower circulating androgen levels by increasing sex hormone-binding globulin, thereby reducing the severity of PCOS symptoms (Adlercreutz, 2007).

Flaxseed Intake in Polycystic Ovary Syndrome (PCOS)

Flaxseed may be helpful for women with PCOS because it improves insulin resistance, supports hormonal balance, and reduces inflammation. Clinical studies indicate that consuming 20–30 g per

day (about 1–2 tablespoons) of ground flaxseed is effective.

Recommended ways to consume flaxseed include:

- Mixing ground flaxseed with yogurt, curd, or smoothies
- Adding it to whole-grain porridge or salads
- Consuming it along with meals to help control blood glucose levels

Ground flaxseed is preferred over whole seeds as it allows better absorption of lignans and omega-3 fatty acids. Regular intake for 8–12 weeks has been associated with improvements in insulin sensitivity, lipid profile, and the LH/FSH ratio in women with PCOS (Jamilian et al., 2020; Najdgholami et al., 2025).

Role of Flaxseed in Cardiovascular Health

Cardiovascular diseases are a major cause of death worldwide. Regular consumption of flaxseed has been linked to several heart-protective effects, including lower total and LDL cholesterol levels, reduced triglycerides, decreased blood pressure, and improved blood vessel function.

A meta-analysis showed that flaxseed supplementation significantly improves blood lipid levels, highlighting its protective role in cardiovascular health (Pan et al., 2009). These benefits are mainly due to the presence of alpha-linolenic acid (ALA) and soluble fiber, which help reduce inflammation and lower the risk of atherosclerosis.

Flaxseed Intake in Cardiovascular Diseases (CVDs)
Flaxseed supports heart health by lowering cholesterol and triglyceride levels, reducing blood pressure, and decreasing inflammation. Studies suggest that a daily intake of 30–50 g of ground flaxseed is effective for cardiovascular protection.

Recommended ways to consume flaxseed include:

- Adding ground flaxseed to bread, chapati dough, oatmeal, or breakfast cereals
- Mixing flaxseed powder with water or milk
- Using flaxseed oil (about 1 tablespoon per day) as a salad dressing; it should not be used for cooking

Meta-analyses show that regular flaxseed intake for at least 12 weeks can significantly reduce LDL cholesterol and blood pressure. These benefits are mainly due to its alpha-linolenic acid (ALA) and soluble fiber content (Pan et al., 2009).

Role of Flaxseed in Cancer Prevention

Flaxseed contains lignans that have oestrogen-regulating and antioxidant properties, which are especially important in hormone-dependent cancers such as breast and prostate cancer. Research suggests that flaxseed may help prevent cancer by slowing tumour growth, reducing the multiplication of cancer cells, and promoting programmed cell death (apoptosis).

Both animal and human studies indicate that regular flaxseed intake may lower cancer risk and improve outcomes, particularly in women with breast cancer (Thompson et al., 2005).

Flaxseed Intake in Cancer Prevention and Management

Flaxseed contains lignans with oestrogen-regulating, antioxidant, and anti-cancer properties, making it beneficial in hormone-related cancers such as breast and prostate cancer.

Recommended intake:

- 25–40 g per day of ground flaxseed
- Recommended ways to consume flaxseed include:
- Mixing it into smoothies, yogurt, or soups
 - Adding it to baked foods prepared at low temperatures
 - Including it as part of a balanced, plant-based diet

Research suggests that consuming flaxseed before and during cancer treatment may help slow tumour growth and improve outcomes, particularly in breast cancer patients (Thompson et al., 2005). Ground flaxseed is preferred over flaxseed oil because lignans are not present in the oil.

Effects on Skin and Hair Health

Flaxseed can support healthy skin and hair because it is rich in omega-3 fatty acids and antioxidants. Its benefits include better skin hydration and elasticity, reduced inflammation in conditions like eczema and acne, and stronger hair follicles with less hair fall.

The omega-3 fatty acids in flaxseed help protect the skin barrier and reduce oxidative stress, which can slow down skin aging (De Spirt et al., 2009).

Flaxseed Intake for Skin Health

Flaxseed can help improve skin hydration, elasticity, and barrier function because of its omega-3 fatty acids and antioxidants.

Recommended intake:

- 1–2 tablespoons of ground flaxseed per day
 - Or 1 tablespoon of flaxseed oil per day
- How to consume:
- Take flaxseed oil capsules or liquid oil with meals
 - Add ground flaxseed to smoothies, yogurt, or other foods

Clinical studies show that taking flaxseed oil for 6–12 weeks can make skin smoother, more hydrated, and less sensitive, while reducing inflammation (De Spirt et al., 2009).

Flaxseed Intake for Hair Health

Flaxseed supports hair by strengthening follicles, improving scalp health, and reducing oxidative stress.

Recommended intake:

- 1–2 tablespoons of ground flaxseed per day
- How to consume:
- Mix ground flaxseed into breakfast foods or beverages
 - Take flaxseed oil capsules as a supplement

The omega-3s in flaxseed improve blood flow to the scalp and reduce inflammation, while antioxidants help protect hair follicles from damage (Goyal et al., 2014).

Immune System Support

Flaxseed can help strengthen the immune system by reducing inflammation. Its omega-3 fatty acids lower pro-inflammatory molecules, and lignans help regulate immune responses. Research shows that regular flaxseed consumption can improve immunity and decrease markers of inflammation in the body (Ren et al., 2016).

Flaxseed Intake for Immune Health

Flaxseed can help support the immune system because it reduces inflammation and positively affects gut health.

Recommended intake:

- 15–30 g of ground flaxseed per day
- How to consume:
- Take flaxseed with meals to improve nutrient absorption
 - Mix it with probiotic foods like yogurt or other fermented foods

Regular consumption of flaxseed has been shown to lower inflammatory markers and strengthen immune response by reducing oxidative stress and regulating cytokines (Ren et al., 2016).

Multidimensional Application of Flaxseed in Industry, Cooking, Medicine and Environment

Flaxseed Oil in Industrial Products

Flaxseed oil is widely used in industry in addition to its nutritional applications. Linseed oil has long been used in the production of paints, varnishes, and protective coatings because it dries quickly when exposed to air. Modified forms such as boiled, borated, and epoxy linseed oils are commonly used. It is also utilized in the manufacture of products such as oilcloth, printing inks, and linoleum (Traditional uses of flax, 2024)

Flaxseed By-Products and Value Addition

Flaxseed cake is a by-product obtained after oil extraction and is rich in nutrients such as residual oil, proteins, and dietary fiber. Because of this composition, it can be used to develop value-added products. Flaxseed cake has potential applications in food products as well as in materials science, including biopolymers and composite materials, supporting sustainable and circular economy practices (Talwar et al., 2025).

Medicinal and Therapeutic Uses

Flaxseed has been widely studied for its health-related benefits. Its high content of alpha-linolenic acid (ALA) and lignans contributes to heart-protective, anti-inflammatory, antidiabetic, and anticancer effects (Firdous & Jorge, 2024). Recent computational studies also suggest that flaxseed may be useful in managing conditions such as diabetes, cardiovascular diseases, inflammatory bowel disorders, and polycystic ovarian syndrome (Joshi & Srivastava, 2024).

Culinary Uses and Food Industry Integration

Flaxseed has a mild, nutty taste and high nutritional value, which makes it suitable for use in cooking and food products. It is commonly added to baked items, cereals, bread, and fortified foods to increase dietary fiber and omega-3 fatty acid content (MDPI Food Applications, 2024). Processed forms such as standardized flaxseed meal (Xan Flax) have also been studied for their effects on food texture and overall sensory quality, especially in products like muffins (Lee et al., 2023).

Nutraceutical Significance

Flaxseed is widely used as a nutraceutical because it contains important bioactive compounds. Lignans and alpha-linolenic acid (ALA) in flaxseed help improve fat metabolism and provide antioxidant effects, which makes flaxseed a common ingredient in dietary supplements and health-focused products (Cholakal et al., 2024). Additionally, flaxseed components obtained through bioprocessing are used as nutraceutical ingredients in functional foods, cosmetics, and supplements (Bioprocessing of functional ingredients, 2025).

Environmental and Sustainability Contributions

Flaxseed by-products, such as defatted flaxseed cake, help reduce waste and support sustainable production. They can be used in animal feed, soil improvement, and biobased materials, which increases resource efficiency and lowers environmental impact (Talwar et al., 2025). In addition, flaxseed mucilage has useful properties for environmental and agricultural uses, including soil conditioning and the development of biodegradable hydrogels (Flaxseed mucilage potential, 2024).

Food Items Made from Flaxseed and Their Nutritional Benefits



flaxseed bread



flaxseed cookies



flaxseed salad



flaxseed
smoothie



Flaxseed-Enhanced Bread and Baked Goods

Adding flaxseed meal or flour to bread, muffins, and other baked items increases fiber, protein, and omega-3 content. Breads made with 5–10% flaxseed flour showed higher fiber and antioxidant levels without changing taste (MDPI, 2024). Flaxseed also helps baked goods stay moist longer and last longer on the shelf (MDPI, 2024).

Benefits: More fiber, protein, minerals, and omega-3 fatty acids (Raghuvanshi, Agrawal, & Mane, 2019).

Flaxseed Cookies and Snacks

Cookies, crackers, and snack bars with flaxseed are healthier options because they contain extra fiber, protein, and ALA. Cookies with 6–12% flaxseed flour had higher omega-3 levels and were liked by consumers (Khouryeh & Aramouni, 2012). Using flaxseed oil instead of shortening improves healthy fat content and reduces saturated fats (Effect of Flaxseed Oil on Cookies, 2012).

Benefits: Better cholesterol levels, antioxidants, and longer feelings of fullness (Rebetiko, Remoortel, Danthine, Paquot, & Blecker, 2017).

Salads and Dressings

Ground flaxseed or flaxseed oil can be added to salads or used as dressing. Flaxseed oil is rich in ALA, which supports heart health and reduces inflammation (Talwar et al., 2025). Sprinkling flaxseed meal adds fiber, minerals, and lignans and helps digestion and satiety (Prachi & Maurya, 2024).

Benefits: Supports the heart, reduces inflammation, and aids digestion (Prachi & Maurya, 2024).

Smoothies, Yogurt, and Breakfast Bowls

Adding flaxseed to smoothies, yogurt, oatmeal, or cereal makes meals more nutritious. It adds fiber, protein, omega-3 fats, and antioxidants without affecting taste (Health.com, 2025).

Benefits: Boosts antioxidants, helps digestion, and improves overall nutrient intake (WebMD, 2024).

Flaxseed as a Binder or Egg Replacement

Flaxseed meal can be mixed with water to make a “flax egg” for vegan baking or veggie patties. It works as a binder while adding fiber and omega-3 fats (Health.com, 2025).

Benefits: Adds plant-based protein, fiber, and heart-healthy fats while replacing eggs in recipes (Healthline, 2024).

II. CONCLUSION

Flaxseed (*Linum usitatissimum*) is a nutrient-dense superfood with diverse applications in health, nutrition, industry, and the environment. It contains important bioactive compounds such as alpha-linolenic acid (ALA), lignans, dietary fiber, and high-quality plant protein, which contribute to heart health, improved metabolism, hormonal balance, and may reduce the risk of certain cancers. Regular consumption of flaxseed has been shown to support cardiovascular function, regulate blood sugar levels, reduce inflammation, and improve digestive health. Its rich content of lignans and ALA also makes it particularly beneficial for women with polycystic ovary syndrome (PCOS), as these compounds can help regulate hormones, improve lipid metabolism, and support insulin sensitivity.

Incorporating flaxseed into common foods such as bread, cookies, muffins, salads, smoothies, and nutritional supplements enhances their nutritional profile by increasing fiber, protein, healthy fats, and antioxidants. Flaxseed by-products, like defatted flaxseed cake and mucilage, provide additional value in industrial and environmental applications, including animal feed, biodegradable materials, and soil conditioning, supporting sustainability and resource efficiency.

Looking forward, there is strong potential for developing functional foods and nutraceuticals that target both overall health and specific conditions like PCOS, diabetes, and obesity. Advanced techniques, such as microencapsulation or combining flaxseed with probiotics, may improve the stability, absorption, and bioavailability of ALA and lignans, further enhancing their health benefits. However,

long-term clinical studies are still needed to determine the optimal form, dose, and duration of flaxseed intake for effectively managing hormonal and metabolic disturbances in PCOS.

Overall, flaxseed represents a safe, natural, and versatile approach to improving nutritional quality, supporting metabolic and hormonal health, and promoting well-being across diverse populations. Its inclusion in the diet and functional food products has promising implications for both preventive and therapeutic nutrition.

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