Nutritional, Medicinal, and Pharmacological Properties of Linseed (*Linum usitatissimum*) for Functional Food Applications: A Comprehensive Review

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Abstract

Linseed (*Linum usitatissimum*) is widely recognized as a valuable functional food ingredient due to its rich nutritional, medicinal, and pharmacological profile, and recent advancements in sensor-based analytical techniques have significantly improved its evaluation for food and nutraceutical applications. The incorporation of smart sensing technologies, including spectroscopic, electrochemical, and biosensors, enables rapid, accurate, and real-time quantification of key bioactive components such as omega-3 fatty acids (α-linolenic acid, ALA), lignans, proteins, dietary fibre, and antioxidants. These constituents are associated with numerous health benefits, including enhanced infant brain development, reduction in blood lipid levels, prevention of cardiovascular diseases, alleviation of constipation, and potential anticancer activity. Sensor-assisted monitoring also facilitates the detection and control of anti-nutritional factors such as cyanogenic glycosides and linatine, thereby ensuring food safety and quality assurance with minimal adverse effects compared to other oilseeds like canola and soybean. Linseed contains approximately 38–45% oil, of which about 52% is polyunsaturated fatty acids (ALA), along with up to 1.3% lignans, 28% dietary fibre, and 20% protein, making it a nutritionally dense ingredient. Furthermore, sensor-based quality assessment tools support process optimization and consistency in the development of linseed-enriched products such as baked goods, muffins, cookies, extruded foods, and meat products, enhancing their nutritional value and consumer acceptability. Thus, sensor-integrated approaches play a crucial role in advancing the analysis, safety evaluation, and commercial utilization of linseed in modern functional food systems.

Keywords: Flaxseed, dietary fibre, lignans, α-linolenic acid, nutritional properties, health benefits

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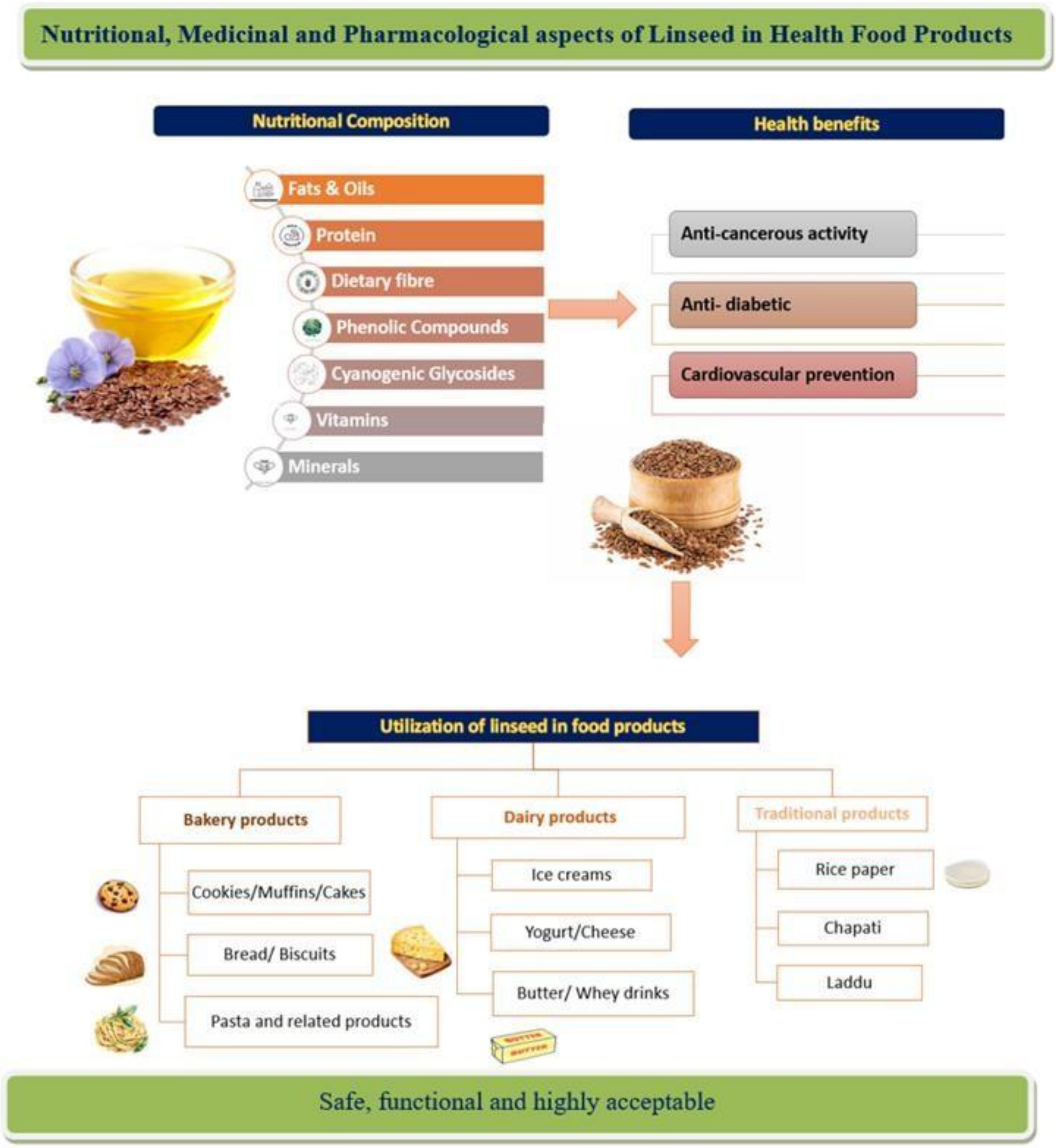
Graphical Abstract



1. Introduction

Linseed or linseed (Linum usitatissimum) is an important fibre and oilseed crop cultivated in nearly 50 countries, predominantly under cool climatic conditions [1]. It belongs to the family Linaceae and is recognized as one of the most significant fibrous oilseed crops worldwide. In India, the terms "linseed" and "flaxseed" are often used interchangeably [3]. Globally, linseed is cultivated over an area of approximately 2.8 million hectares, with a total production of around 3.97 tonnes. Major producing countries include Canada, Kazakhstan, China, and Russia, with India also being a key contributor to global production. Canada accounts for nearly 28% of the total global linseed production, followed by China (14%) and India (7%). In India, linseed is cultivated over an area of about 238,731 hectares, with an annual production of 166,753.2 tonnes as reported in 2023 [2]. The major linseed-producing states in India include Rajasthan, Madhya Pradesh, Bihar, West Bengal, Maharashtra, Odisha, Uttar Pradesh, Karnataka, and Himachal Pradesh [150]. Historically, linseed has been utilized since prehistoric times, not only for industrial applications such as paints, drying oils, printing inks, and coatings, but also for its nutritional

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and medicinal properties, highlighting its long-standing significance in human diets and traditional healthcare systems [145].

Linseed (*Linum usitatissimum*) is native to the Mediterranean region and West Asia and is primarily cultivated for its oil and linen fibre [4]. It is one of the richest plant-based sources of α-linolenic acid (ALA), constituting approximately 45–52% of linseed oil. Nutritionally, linseed is a dense source of protein, fat, and dietary fibre, containing about 4–8% moisture, 20–28% total dietary fibre, 20–25% protein, 30–40% oil, and 3–4% ash. The oil is a rich source of fat-soluble vitamins, including vitamins A, D, and E, along with essential amino acids and minerals. Its fatty acid profile comprises approximately 18% monounsaturated fatty acids, 73% polyunsaturated fatty acids, and 9% saturated fatty acids [5].

Recent studies have highlighted multiple health benefits of linseed, largely attributed to key bioactive components such as lignans (secoisolariciresinol diglucoside, SDG), non-starch polysaccharides (dietary fibre or gum), and α-linolenic acid (ALA) [6]. Linseed is among the most widely available plant sources of essential fatty acids, including ALA and linoleic acid, which are vital for human health [7]. Beyond its conventional use for oil extraction and meal, linseed is increasingly incorporated as a functional ingredient in various food products. Due to its rich nutritional profile, it exhibits antioxidant, anticancer, and antihypertensive properties [8]. Regular consumption of 2–3 g of linseed per day has been reported to increase high-density lipoprotein (HDL) levels and reduce low-density lipoprotein (LDL) levels [9]. Additionally, it plays a role in managing asthma, diabetes, arthritis, cardiovascular diseases, and supports wound healing [10].

With the growing demand for functional foods, linseed has gained significant importance as a nutritionally enriched ingredient in bakery products (bread, cookies, and muffins), meat products, salad dressings, extruded foods, and ready-to-eat products [11]. Comprehensive studies have also identified the presence of various bioactive compounds such as linoleic acid, cyanogenic glycosides, cyclic peptides, alkaloids, polysaccharides, and trace elements like cadmium [146]. Therefore, linseed holds substantial commercial, nutritional, and pharmacological importance as a multifunctional crop [147]. In the current health-conscious era, despite its rich omega-3 fatty acid content and therapeutic potential, consumer awareness remains limited, emphasizing the need to promote its utilization as a functional food ingredient with significant health benefits.

2. Nutritional Properties

Linseed contains several health-promoting components, including proteins, dietary fibre, fats, complex carbohydrates, cyanogenic glycosides, phenolic acids, essential vitamins (A, C, and E), and minerals. It possesses approximately 36–40% fat, which serves as an important source of essential polyunsaturated fatty acids (PUFAs) that cannot be synthesized by the human body. In addition, linseed comprises about 28% total dietary fibre, 20% protein, 41% fat, 7.7% moisture, and 3.4% mineral content, making it a highly nutritious functional food ingredient [12–14].

2.1 Fats/Oils

The fatty acid profile of linseed varies depending on its type. Approximately 75% of the total oil content is located in the cotyledons, while the remaining portion is distributed in the seed coat and endosperm [15]. Although linseed oil is traditionally used for cooking in northern China, its application is limited due to its high oxidative instability [16]. Linseed is one of the richest sources of fats, particularly polyunsaturated fatty acids (PUFAs), including omega-3 fatty acids such as α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), along with monounsaturated fatty acids (MUFAs) such as palmitic, oleic, and stearic acids, and omega-6 fatty acids like linoleic acid. The extracted linseed oil typically contains about 9% saturated fatty acids, 18% MUFAs, and 73% PUFAs [17]. The composition of saturated and unsaturated fatty acids in linseed is illustrated in Figure 1. Linseed is considered a valuable plant-based crop due to its high omega-3 fatty acid content, which plays significant biological roles in the human body. It is recognized as a superior source of PUFAs compared to corn, soybean, marine algae, or fish oil [18,19]. The Food and Drug Administration (FDA) has reported that omega-3 fatty acids can help reduce the risk of several chronic diseases, including cardiovascular diseases, gastrointestinal disorders, diabetes, and osteoporosis. The molecular structures of EPA and DHA are presented in Figure 2. Long-chain polyunsaturated fatty acids (LC-PUFAs), particularly EPA and DHA, are more effectively

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absorbed in the presence of ALA, which also contributes to reducing disease risk. Nutrition experts recommend an optimal dietary ratio of omega-6 to omega-3 fatty acids in the range of 5:1 to 10:1.

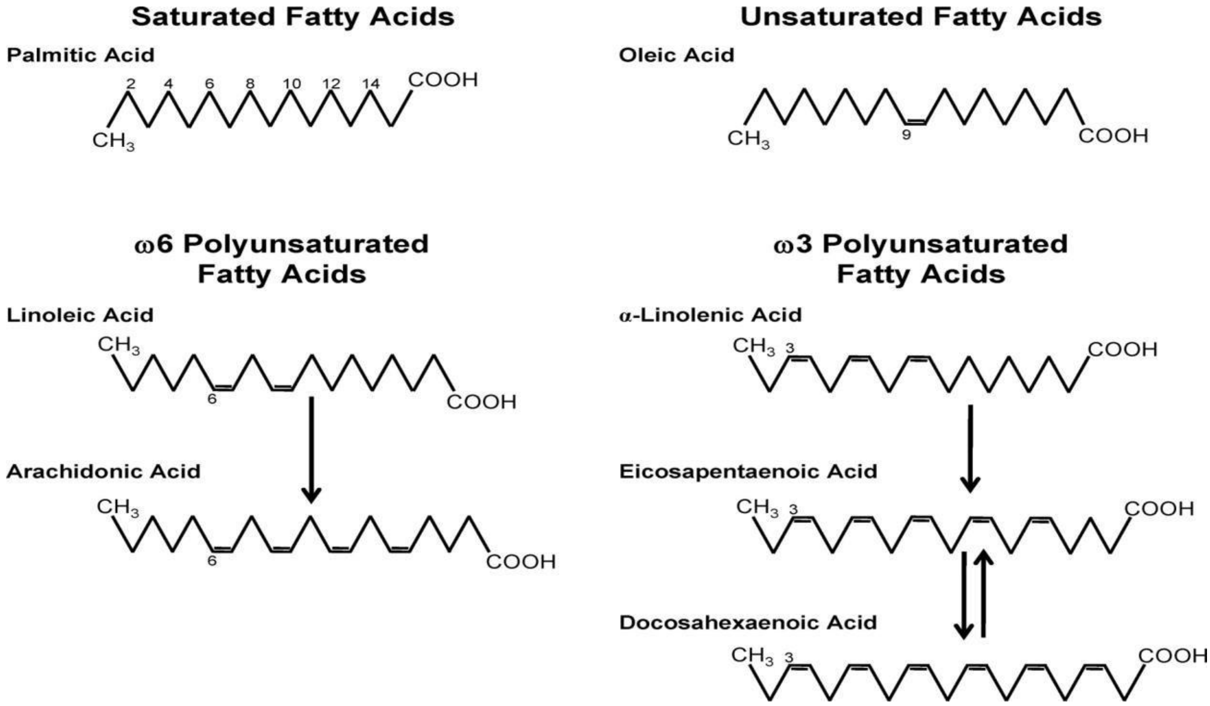

Figure 1: Saturated and unsaturated fatty acids of linseed

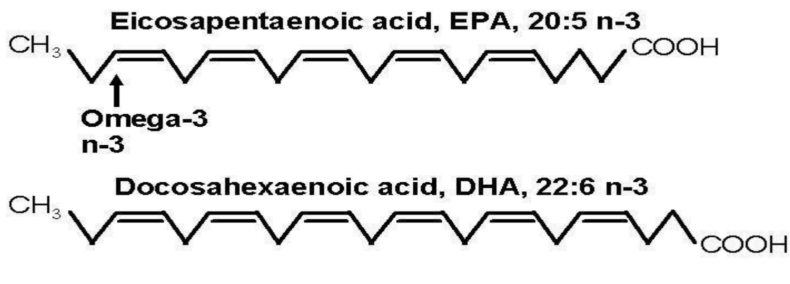

Figure 2: Structures of EPA and DHA

Linseed contains α-linolenic acid (ALA), an essential polyunsaturated fatty acid that cannot be synthesized by the human body and must be obtained through diet. ALA plays a crucial role as a precursor in the biosynthesis of eicosanoids, which are hormone-like compounds involved in regulating immune and inflammatory responses in the human body [20]. The distribution of triacylglycerols in linseed is presented in Table 1.

Table 1: Triacylglycerols distribution in Linseed [100]

Triacylglycerols (TG)	%	Triacylglycerols (TG)	%
LnLnLnL	30.4	OLnP	3.1
LaLnLn	18.7	LnLaP	3.0
OLnLn	13.5	SLaLa	1.1
LnLnP	6.9	OLaLa	1.0
OLaLn	5.9	LaLaLa	0.9
LaLaLn	5.3	OLaO	0.8
OLnO	4.2	LaOP	0.6

SLnLn	4.1	PLnP	0.5

P, palmitic acid; S, stearic acid; O, oleic acid; La, linoleic acid; Ln, linolenic acid

2.2 Protein

The protein content of linseed, an essential macronutrient for growth, ranges from 10.5% to 31.0% [21]. Approximately 56–70% of the total protein is concentrated in the cotyledons, with the remainder present in the seed coat and endosperm [22]. The major protein fractions in linseed include albumin (26.6%) and globulin (73.4%) [23], and these proteins are primarily stored in the cotyledons [24]. Due to the absence of gluten, linseed is widely utilized as an important ingredient in gluten-free diets. The protein composition of major linseed cultivars grown in different countries is presented in Table 2. Madhusudhan and Singh [25] reported a protein content of 21.9% in the Khategaon variety cultivated in India, while another study indicated an average protein content of 19.5% in linseed [26]. Variations in protein content are influenced by genetic, environmental, and processing factors. In Canadian linseed varieties, protein content estimation from nitrogen was calculated using a conversion factor of 6.50 as reported by Oomah and Mazza [21], while a factor of 5.41 was also used by the same authors [27], as shown in Table 2. Linseed proteins are rich in amino acids such as arginine, glutamic acid, and aspartic acid, but are limited in lysine, cystine, and methionine [28]. Germination of linseed for up to 8 days significantly enhances the amino acid profile, increasing levels—particularly glutamine and leucine—by up to 15 times [29]. The amino acid composition of linseed varieties from different countries is summarized in Table 3. Changes in linseed protein with temperature can be analyzed using differential scanning calorimetry, where protein denaturation at higher temperatures is associated with various chemical interactions. Weakening of hydrophobic interactions and protein aggregation leads to exothermic changes, whereas the breakdown of hydrogen bonds results in endothermic transitions [30]. The outer and inner structure of linseed is illustrated in Figure 3. Linseed protein exhibits an amino acid sequence comparable to that of soybean protein and is considered among the most nutritionally valuable plant proteins, with a biological value (BV) similar to soybean protein [151]. Owing to its high protein content, linseed has been found effective in reducing triglyceride and plasma levels compared to soy protein and casein [31]. Additionally, its rich omega-3 fatty acid content provides nutritional benefits in animal feed, enhancing the overall quality and value of animal-derived products [152].

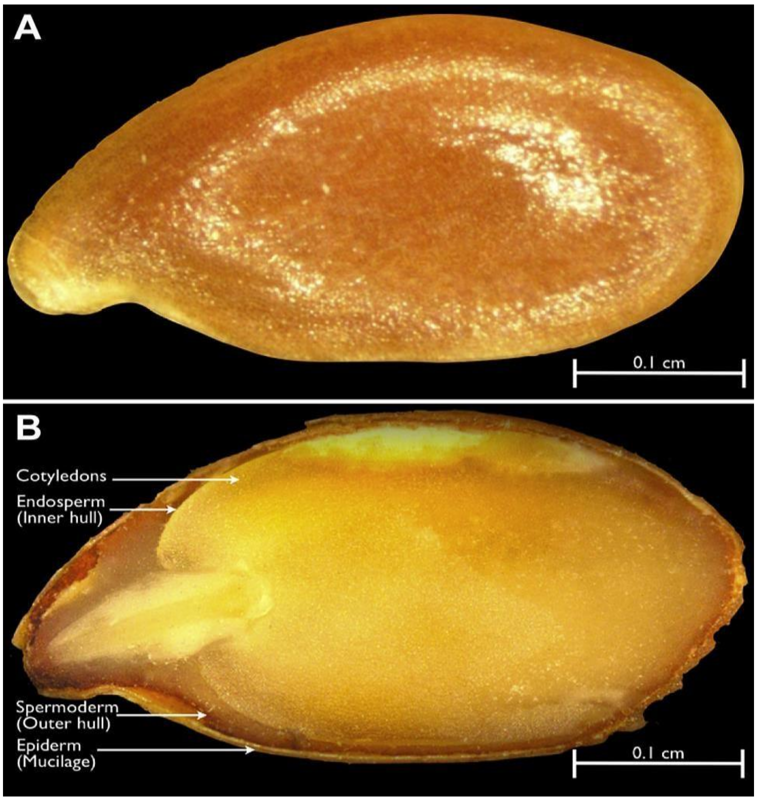

Figure 3: Outer and Inner Structure of Linseed

Table 2: Protein Content of different Linseed Varieties¥

Poland		Canada		USA	
[101]		**[21]**		**[102]**	
Variety	**Protein %**	**Variety**	**Protein€ %**	**Variety**	**Protein %**
Avangard	24.7	Linott	19.81	Clark	27.3
Reina	25.2	Noralta	19.82	Culbert	30.0
Viking	25.6	DuVerin	18.42	DuVerin	31.6
Ottawa	25.8	McGregor	19.07	Flor	31.0
Hera	27.4	NorLin	19.49	Linott	26.9
Zielona	27.9	NorMan	19.45	Linton	29.4
Bionda	28.0	Vimy	19.03	McGegor	27.1
LCSD200	28.2	Andro	19.89	Neche	29.5
Svapo	28.6	Somme	19.67	Norlin	28.1
– –	–	Flanders	19.33	Norman	27.0
–	–	AC Linora	20.18	Verne	29.5

¥Protein contents are calculated on dry basis.

€N×6.5.

Table 3: Amino acid content (g/100 g protein) of different linseed varieties

	Poland	Canada			India
	[101]	**[21]**			**[103,104]**
Amino acid	**LCSD 200**	**Norlin**	**Foster**	**Omega**	**Khategaon**
Ala	5.40	4.4	4.7	4.5	4.3
Arg	9.75	9.2	10.0	9.4	11.5
Asp	10.40	9.3	9.3	10.0	9.7
Cys	–	1.1	1.8	1.1	–
Ser	–	4.5	4.7	4.6	5.1
Glu	22.50	19.6	20.0	19.7	19.8
Gly	6.41	5.8	5.9	5.8	4.8
His	1.42	2.2	2.1	2.3	2.5
Leu	–	5.8	6.0	5.9	5.8
Ile	3.53	4.0	4.1	4.0	4.6
Lys	1.80	4.0	4.0	3.9	4.1
Met	1.44	1.5	1.4	1.4	1.7

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Phe	4.9	4.6	4.8	4.7	5.9
Pro	3.16	3.5	3.8	3.5	4.6
Thr	–	3.6	3.8	3.7	3.9
Tyr	1.53	2.3	2.4	2.3	3.3
Val	5.69	4.6	5.1	4.7	5.6

2.3 Dietary Fibre

Dietary fibre consists of non-digestible plant carbohydrates and associated components that remain intact during digestion. In linseed, a significant portion of fibre and certain pigments may be reduced during the dehulling process, which can influence its overall quality. Linseed is considered one of the richest sources of plant lignans, particularly secoisolariciresinol diglucoside (SDG), along with phenylpropanoids, flavonoids, and tannins, contributing to its functional properties [148,149]. It contains both soluble and insoluble dietary fibres, each providing distinct physiological benefits. Insoluble fibre promotes laxation by increasing fecal bulk and reducing intestinal transit time, thereby preventing constipation [32], while soluble fibre plays a role in lowering blood cholesterol levels and regulating blood glucose [33]. The carbohydrate content of linseed ranges from approximately 22.92% to 29.67%. About one-third of the fibre is soluble, exhibiting antidiabetic and hypocholesterolemic effects, whereas the remaining insoluble fraction acts as a bulking agent, improving digestive health [34].

Linseed dietary fibre is rich in pentosan sugars, with the hull containing about 2–7% soluble fibre, commonly referred to as mucilage or gum [35]. This soluble fraction can be extracted using hot water at 90–95°C for 50–60 minutes, yielding approximately 13–14% mucilage [36–38]. The soluble fibre consists of acidic polysaccharides such as D-xylose, L-rhamnose, L-galactose, and L-fructose, along with neutral polysaccharides including D-xylose/D-galactose and L-arabinose. In contrast, the insoluble fraction comprises cellulose, lignin, and acid detergent fibre in the ranges of 7–11%, 2–7%, and 10–14%, respectively [36].

Separation of linseed mucilage can be achieved through both physical and chemical methods. Physical techniques include heating, filtration, centrifugation, and drying processes such as steam heating, freeze drying, microwave drying, and spray drying, which are widely applied in industrial practices [38]. Chemical extraction using sodium bicarbonate enhances mucilage recovery compared to water extraction alone [39]. Enzymatic treatments using protease and α-amylase further aid in isolating gum from the seed coat. The extracted mucilage exhibits desirable functional properties, including foam formation, emulsification, and salt tolerance. It remains stable over a wide pH range (6–12), displaying Newtonian behavior at concentrations below 0.2% (w/v) and shear-thinning characteristics at higher concentrations [40,41].

2.4 Phenolic Compounds

Linseed contains three major classes of phenolic compounds, namely flavonoids, lignans, and phenolic acids. Among these, lignans exhibit strong antioxidant as well as anticancer properties [42,43]. The biosynthesis pathway of flaxseed lignans is presented in Figure 4, where they act as precursors to secoisolariciresinol diglucoside (SDG), which is found in linseed at concentrations 75–800 times higher than in most other foods [44]. The total phenolic content in defatted and non-defatted linseed extracts has been reported as 13.23% and 5.42%, respectively, with defatted linseed flour containing approximately 1–3% SDG. SDG has been shown to help prevent the development of diabetes and atherosclerosis [45,46], along with providing additional benefits such as improving cholesterol levels and blood lipid profiles [47]. Both defatted and non-defatted linseed extracts contain a wide range of phenolic acids, including coumaric, ferulic, caffeic, gallic, chlorogenic, p-hydroxybenzoic, protocatechuic, vanillic, and sinapic acids [48,49], as summarized in Table 4.

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Table 4: Phenolic Compounds contents (mg/100g) [48]

Phenolic compounds	NDFE	DFE
Ferulic acid	161	313
Coumaric acid	87	130
Caffeic acid	4	15
Chlorogenic acid	720	1435
Gallic acid	29	17
Protocatechuic acid	7	7
p- Hydroxybenzoic acid	1719	6454
Sinapic acid	18	27
Vanillin	22	42
Total	2767	8440
SDG	2653	4793

NDFE= Non-defatted flaxseed extract; DFE= Defatted flaxseed extract.

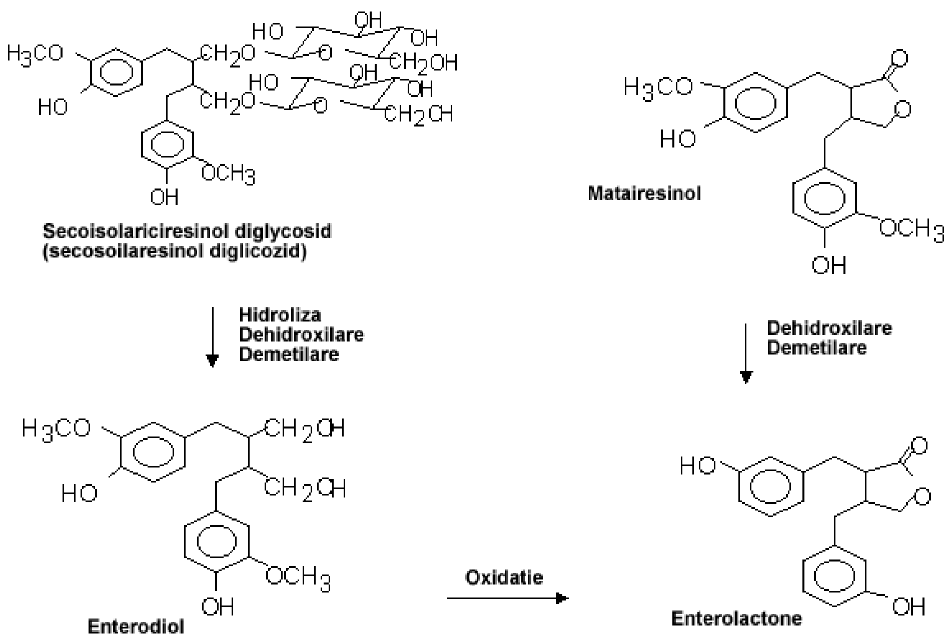

Figure 4: Biosynthesis pathway of flaxseed lignans (Ford *et al.,* 2001)

2.5 Cyanogenic Glycosides

Linseed, despite being a rich source of nutrients, contains a considerable amount of cyanogenic glycosides. The major cyanogenic compounds present in linseed include linustatin, linamarin, neolinustatin, and lotaustralin, which upon hydrolysis release toxic hydrogen cyanide (HCN), as illustrated in Figure 5. The cyanide content varies depending on the cultivar and typically ranges from 124 to 196 mg/g (Table 5). These compounds are degraded in the intestines by the enzyme β-glucosidase; however, if absorbed in sufficient quantities, HCN can exert potent respiratory inhibitory effects [50], limiting the widespread use of linseed meal. Processing techniques play a crucial role in reducing these toxic constituents, as methods such as steaming are effective in producing cyanogen-free linseed meal. Moreover, cyanogenic compounds are generally not detectable in processed linseed oil, making it safer for consumption.

Table 5: Cyanogen content (mg/100g seed) in different linseed varieties

	[50]	[105]		
Cultivar	**Cyanide**	**Linamarin**	**Linustatin**	**Neolinustatin**
Ac Linora	14.5	19.8	269	122
Andro	19.6	16.7	342	203
Flanders	12.5	13.8	282	147
Linott	14.4	22.3	213	161
McDuff	15.4	–	–	–
McGregor	13.8	25.5	352	91
Noralta	–	20.3	271	163
Norlin	15.1	NDa	295	201
NorMan	12.4	NDa	231	135
Somme	16.6	27.5	322	149
Vimy	13.7	31.9	262	115

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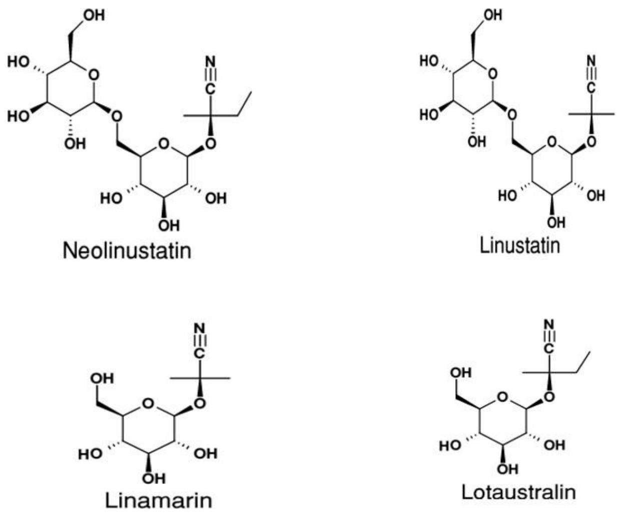

Figure 5: Structures of Cyanogenic Glycosides

2.6 Other Components

2.6.1 Vitamins

Linseed contains both water- and fat-soluble vitamins in small quantities. It is particularly rich in γ-tocopherol, the predominant form of vitamin E, which functions as a potent antioxidant protecting cellular lipids and proteins from oxidative damage [51]. Tocopherol content varies depending on factors such as seed variety, cultivation conditions, and processing methods [52,53]. The γ-tocopherol content ranges from 0.7–3.2 mg per tablespoon of milled linseed or 8.5–39.5 mg per 100 g of seeds [6]. Studies have reported total tocopherol content of up to 12.74

mg per 100 g of seed [54]. Additionally, linseed contains small amounts of vitamin K (approximately 0.3 μg), present as phylloquinone, further contributing to its nutritional value.

2.6.2 Minerals

Linseed is also a rich source of essential minerals, including sodium (27 mg/100 g), calcium (236–250 mg/100 g), magnesium (350–431 mg/100 g), and phosphorus (approximately 650 mg/100 g) [55]. It is particularly notable for its high potassium content, ranging from 56 to 920 mg/100 g, which is comparable to that of bananas on a dry weight basis. Increased potassium intake is associated with reduced risk of stroke, improved vascular function, decreased platelet aggregation, and lower levels of oxidative stress in the bloodstream [56]. Thus, the mineral composition of linseed further enhances its role as a nutritionally valuable and health-promoting food ingredient.

3. Health Benefits of Linseed

Linseed has been utilized in both human and animal nutrition since ancient times and is increasingly gaining attention due to its rich nutritional and therapeutic properties. The growing popularity of linseed oil is primarily attributed to its high content of α-linolenic acid (ALA), an essential omega-3 fatty acid. Linseed is a valuable source of phenolic compounds, dietary fibre, oil, protein, and other bioactive constituents, making it a unique oilseed with exceptionally high levels of lignans and ALA. It contains approximately 28% dietary fibre, which plays a crucial role in improving digestive health and reducing the risk of colon cancer. Linseed protein, comparable in quality to soy protein, along with its phenolic compounds and dietary fibre, contributes to improved bowel movement, reduced constipation, and cholesterol regulation. Owing to these properties, linseed is widely recognized for its significant dietary and health benefits [157].

3.1 Cancer Prevention

Cancer is a complex disease characterized by stages such as initiation, promotion, proliferation, and metastasis, making its prevention and treatment challenging. Linseed has shown promising potential in cancer prevention due to its rich antioxidant content [57]. Processing techniques such as germination enhance the nutritional profile of linseed by increasing enzyme activity, amino acid availability, and vitamin content, while also improving bioavailability. Sprouting has been reported to double the antioxidant capacity of linseed and reduce antinutritional factors such as enzyme inhibitors and phytic acid, thereby enhancing nutrient absorption. Studies suggest that lifestyle and dietary modifications can prevent approximately 30–40% of cancers. Lignans present in linseed exhibit strong antioxidant properties and may help inhibit cancer initiation [46,58,42,43]. Compounds such as enterodiol and enterolactone have been shown to suppress the growth of prostate cancer cell lines [59], and higher levels of enterolactone have been associated with reduced prostate cancer risk [60]. Experimental studies have also demonstrated the effectiveness of linseed in reducing the incidence of skin and colon cancers [6,55]. Additionally, soluble fibre and other bioactive components in linseed help regulate insulin activity and plasma glucose levels, contributing to reduced postprandial blood glucose response [17,61]. Clinical observations indicate that regular consumption of linseed can reduce blood glucose levels and inhibit cancer cell growth, as evidenced in both human and animal studies [17,62,63].

3.2 Cardiovascular Diseases

Regular consumption of linseed has been associated with significant improvements in cardiovascular health. Intake of 50 g/day of roasted linseed for four weeks has been reported to reduce plasma low-density lipoprotein (LDL) cholesterol by approximately 8% in healthy individuals [17]. Furthermore, consumption of linseed-enriched foods such as muffins, bagels, and bars containing about 30 g of linseed has demonstrated a significant reduction in both systolic and diastolic blood pressure in patients with hypertension and pulmonary artery disease. These findings highlight the role of linseed in lowering cardiovascular risk and improving overall heart health [64].

3.3 Diabetes Prevention

Linseed plays an important role in the prevention and management of diabetes due to its high soluble fibre content and low glycemic index. Diets rich in soluble fibre help regulate blood glucose levels and mitigate the metabolic effects of insulin resistance. Studies have shown that consumption of 50 g/day of ground linseed for four weeks significantly reduces blood glucose levels [17]. Similar improvements have been observed in postmenopausal women consuming 40 g/day of linseed-enriched diets [65]. Additionally, incorporation of linseed flour (25%) in bread formulations has been shown to reduce glycemic response by up to 28% compared to control bread [61]. These findings indicate that linseed can be effectively used as a functional food ingredient for managing blood sugar levels and reducing the risk of diabetes.

4. Assessing the Effects of Higher Linseed Intake on Health

The impact of increased linseed consumption on human health has been evaluated in several studies, highlighting both its benefits and potential risks. A study conducted by Haque (2024) [153] reported that consumption of up to 45 g of whole linseed per day provides significant health benefits for the adult population in Denmark. The study estimated that increased linseed intake among individuals aged 15–74 years could result in a reduction of up to 670 disability-adjusted life years (DALYs) per 100,000 people annually. This health impact assessment considered both the beneficial effects of dietary fibre and the potential risks associated with cadmium exposure [153].

Linseed contains trace amounts of cadmium, a potentially toxic heavy metal [154]. Due to its slow excretion, cadmium has a long biological half-life of approximately 10–30 years [155]. Prolonged exposure to cadmium can lead to damage of the kidney's proximal tubular cells and may eventually result in renal dysfunction. Despite these concerns, the overall health benefits of linseed consumption remain significant. When α-linolenic acid (ALA) was included in the assessment, the positive health impact was further enhanced.

Although high intake levels (>27 g/day) may exceed the tolerable weekly intake (TWI) for cadmium under certain conditions, its overall contribution to adverse health effects was found to be minimal. The combined benefits of increased dietary fibre and ALA intake outweigh the potential risks associated with cadmium exposure. Therefore, even at higher consumption levels, linseed intake demonstrates a net positive effect on overall health, supporting its use as a functional food ingredient for improving nutritional status and reducing disease risk.

5. Utilization of Linseed in Food Products

5.1 Cookies, Muffins, and Cakes

Cookies are widely consumed snack foods around the world and are typically defined as firm, sweet or semi-sweet baked products with a variety of flavors and ingredients such as chocolate and nuts [66]. They are characterized by high sugar and fat content, low moisture levels, extended shelf life, and desirable sensory qualities. Due to their low water content, cookies are microbiologically more stable than products like cakes and bread. They are often described as thin, crisp, and hard baked products [67]. According to Hoseney and Zhang [68], cookies are made from a semi-fluid mixture of flour, sugar, shortening, water, and sodium bicarbonate, which solidifies upon heating, leading to dough development, moisture loss, and browning.

The incorporation of linseed into cookies has been widely studied to enhance their nutritional value, particularly due to its high omega-3 fatty acid content. Hussain et al. [69] developed cookies using composite flours containing 5–30% full-fat linseed flour and observed that overall quality decreased with higher supplementation levels; however, cookies with up to 20% linseed flour remained acceptable. Similarly, the inclusion of linseed at 6% and 12% levels did not significantly affect consumer acceptance in terms of sensory and physical attributes [70]. Linseed oil has also been used to replace shortening up to 30%, resulting in a 14.14% increase in omega-3 fatty acids, although it reduced the spread factor of cookies [71]. Omega-3 enriched cookies showed acceptable quality, despite slight reductions in spread ratio and visual appeal compared to control samples [72].

The addition of linseed in bakery and cereal-based products significantly improves their nutritional profile. For example, incorporation of linseed in bread enhances dough properties such as stickiness, crumb structure, and water absorption [73]. Although linseed-enriched muffins (7.3–15.5%) showed slightly lower sensory acceptability than control samples, they still contributed significantly to dietary fiber intake, meeting up to 16% of daily requirements, as presented in Table 6 [74]. Overall, linseed serves as a valuable functional ingredient in baked products, improving both nutritional quality and health benefits.

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Table 6: Utilization of different forms of linseed in bakery products

Product	Linseed form	Level of addition (%)	References
Biscuit	Linseed flour	20-40	[89]
	Linseed meal and oil	15 and 100	[106]
	Linseed flour	11-43	[78]
	Linseed flour	5-15	[107]
	Linseed bran	5-20	[108]
	Grinded linseed	10-30	[109]
	Linseed powder	10-25	[110]
Cookies	Roasted linseed flour	5-20	[111]
	Linseed flour	0-18	[70]
	Linseed oil	5-50	[71]
	Roasted linseed flour	5-30	[112]
	linseed flour and wheat flour	5-30	[69]
	Full fat linseed flour	20	[72]
	Roasted linseed flour	5-15	[113]
Sugar snap cookies	Barley, linseed, oats and soya bean flour blend	10-20	[111]
Cake and Cookies	Linseed flour	5-25	[114]
Cake	Linseed flour	5-45	[115]
Carrot cake (gluten-free)	Linseed meal	9.48	[116]
Muffins	Linseed flour	33-66	[117]
	Raw and roasted linseed flour	10-40	[118]
	Ground linseed	7.3-15.5	[74]

5.2 Biscuits

Biscuits are popular traditional food products in India due to their convenience and adaptability for fortification with functional ingredients [75]. Incorporation of linseed flour (11–43%) into biscuits enhances moisture, ash, fat, protein, and dietary fibre content while reducing carbohydrate levels. Additionally, antioxidant activity and phenolic content increase with higher linseed incorporation. However, higher fortification levels may result in darker color and slight changes in sensory properties. Optimum quality in terms of both nutrition and acceptability has been reported at around 10% linseed incorporation [76–78].

5.3 Bread

Bread is one of the most widely consumed staple foods worldwide due to its nutritional value, affordability, and convenience. Its quality is generally evaluated based on parameters such as volume, texture, color, and flavor [79]. The incorporation of linseed into bread formulations has been explored to enhance its functional and nutritional properties. Studies have shown that both ungerminated and germinated linseed meal, when added at levels of 5, 10, 15, and 20%, can be used in the preparation of functional whole wheat bread [80]. Among these, the inclusion of 10% linseed meal (both germinated and ungerminated) resulted in bread with desirable baking performance and sensory acceptability compared to control samples. Additionally, the shelf life of whole wheat bread was extended up to seven days at room temperature and up to ten days under refrigerated conditions.

Linseed is commonly used as a key ingredient in multigrain bread formulations due to its ease of incorporation and high water-binding capacity, which helps retain moisture and delay staling. This property allows linseed to act as a natural preservative, thereby reducing spoilage and improving product stability. Consequently, linseed not only enhances the nutritional profile but also improves the sensory quality of baked products [81]. Furthermore, the addition of 15% linseed to wheat flour, as shown in Table 7, significantly improved the nutritional composition of various products such as pizza, pan bread, and tahina, leading to increased fat, protein, fiber, and ash content, while reducing carbohydrate levels [82].

Table 7: Utilization of different forms of linseed in different types of breads

Product	Linseed form	Level of addition (%)	References
Bread	Linseed flour	15-30	[117]
Bread	Raw and roasted ground linseed	5-15	[119]
Bread	Linseed flour	15	[120]
Bread	Full fat and defatted linseed flour	15	[121]
Chinese steamed bread	Linseed hull extracts	1	[122]
Chinese steamed bread	Ground linseed	20	[123]
Yeast bread	Milled linseed (flour)	15-25	[124]
Taftoon bread	Coated and uncoated ground linseed	5-25	[125]
Pan bread	Roasted linseed flour	10-20	[82]
Pan bread	Partially defatted and full fat	4-20	[126]
Unleavened flat bread	Full fat and partially defatted linseed flour	4-20	[127]
Pita bread	Linseed cake flour	5-20	[128]
Pizza	Roasted linseed flour	10-20	[82]
Bagels	Milled linseed	23	[129]
Bagels/pretzel-type bakery product	Linseed flour	5-15	[130]

5.4 Dairy Products

Pasta is considered one of the most widely consumed staple foods globally and is traditionally prepared from water and coarse durum wheat semolina [87]. To enhance its nutritional value, conventional pasta has been supplemented with dietary fiber and omega-3 fatty acids through the incorporation of linseed. However, the addition of linseed influences processing and product characteristics, including extrusion, drying, and cooking behavior, as well as the retention and release of free fatty acids during in vitro digestion. These changes are mainly attributed to gluten dilution, physical interference with gluten network formation, and possible chemical interactions between semolina and linseed components during pasta production [88].

In addition to pasta, linseed has been incorporated into a variety of traditional foods to improve their functional and nutritional properties. Products such as vegetable chilla, manchurian, and khakhra have been developed using different levels of linseed flour, as shown in Table 9 [89]. Other food preparations, including vermicelli, vegetable soup, and bhelpuri chaat enriched with linseed, have demonstrated good nutritional quality and functional benefits, particularly due to their low-fat content and potential for promoting heart health [90]. Moreover, flax chutney powder, prepared by blending roasted linseed with selected spices, has been developed as a palatable functional food with enhanced nutraceutical properties [91]. Linseed flour has also been successfully incorporated into animal-based products such as beef patties, improving their energy value and polyunsaturated to saturated fatty acid ratio [34].

Table 8: Utilization of different forms of linseed in different dairy products

Product	Linseed form	Method of processing	Level of addition (%)	References
Milk	Linseed lignan	Heat treatment	1%	[85]
Yogurt	Linseed lignan	Fermentation	100 mg	[85]
Cheese	Linseed lignan	Pasteurization and fermentation	1 g/10 L	[85]
Ice cream	Linseed oil	Freezing	0–12%	[84]
Dahi	Microencapsulated linseed oil powder (MEFOP)	Fermentation	1–3%	[86]
Whey drinks	Linseed lignan	Pasteurization	10 mg/100 ml	[85]
Butter	Linseed additive	–	0.8–1.6%	[131]

5.5 Pasta and Other Food Products

Pasta, typically prepared from durum wheat semolina, is a globally popular food product [87]. Enrichment with linseed improves its nutritional quality by increasing dietary fibre and omega-3 fatty acid content. However, linseed incorporation may influence the structural and cooking properties of pasta due to gluten dilution and interactions between linseed components and wheat proteins [88]. Linseed has also been incorporated into traditional snacks such as chilla, khakhra, and manchurian, as well as ready-to-eat products like soups and bhelpuri, enhancing their functional and nutritional value [89,90]. Additionally, products like flaxseed chutney powder have been developed, offering improved nutraceutical benefits [91]. Linseed flour is also used in meat products, such as beef patties, to enhance fatty acid composition and nutritional value [34].

Table 9: Utilization of different forms of linseed in pasta and other food products

Product	Linseed form	Level of addition (%)	References
Pasta	Linseed flour	15%	[132]
Pasta	Linseed flour	5-20%	[133]
Pasta	Defatted milled linseed	10 and 30 g	[133]
Puffs	Linseed with corn meal	15%	[134]
Noodle	Linseed flour	10%	[135]
Macaroni	Ground whole linseed and ground linseed hull	15%	[136]
Corn and linseed snacks	Linseed flour	16%	[137]
Extruded snacks	Linseed flour	0-20%	[138]
Bean snack	Milled linseed	5-20%	[139]
Spaghetti	Ground linseed	5-15%	[140]
Cereal Based products	Linseed meal	9%	[141]
Chutney powder	Linseed flour	50	[91]
Vegetable chilla	Linseed flour	20-40	[89]
Energy bar	Linseed flour	0-20	[142]
Manchurian	Linseed flour	20-40	[89]
Tahina	Roasted linseed flour	25-100	[82]
Dry-fermented sausages	Linseed oil	3.3	[143]
Vermicelli	Linseeds	10	[90]
Bhelpuri chat	Linseeds	10	[90]
Vegetable soup	Linseeds	15	[90]

5.6 Rice Paper

Rice paper is a traditional food widely consumed in Southeast Asia and is gaining popularity globally [92]. Conventional rice paper is primarily composed of starch and lacks essential nutrients [93,94]. Incorporation of linseed powder in rice paper significantly improves its nutritional profile by increasing dietary fibre and omega-3 fatty acid content. Omega-3 enriched rice paper has shown improved sensory characteristics, including taste and texture, compared to traditional rice paper [95].

5.7 Chapati

Chapati is a staple unleavened flatbread consumed widely in India, made primarily from whole wheat flour [96]. Its quality is determined by texture, pliability, and color [97]. Nutritional enhancement of chapati has been achieved by incorporating various flours, including linseed flour [97–99]. Linseed-enriched chapati requires less water for dough preparation and exhibits improved texture and softness compared to control samples. The presence of non-starch polysaccharides aids in moisture retention, maintaining acceptable texture for up to 8 hours of storage. However, prolonged storage may result in hardening due to reduced water absorption. Overall, linseed incorporation improves nutritional value while maintaining acceptable sensory properties [72].

5.8 Laddu

Linseed-enriched laddu is a nutritionally enhanced traditional product with improved protein content (approximately 7.66%) and calorific value (around 455 kcal). Consumption of such products contributes significantly to daily protein and energy requirements. Sensory evaluation indicates that linseed laddus are comparable to control samples in terms of taste, texture, and overall acceptability, even during storage. The presence of additional fats from linseed improves texture and flavor, while moisture reduction during storage enhances appearance. These products remain acceptable for up to three months and provide a convenient way to incorporate omega-3 fatty acids into the diet [72].

6. Conclusion

Linseed (*Linum usitatissimum*) has not been widely recognized as a staple food crop, mainly due to certain inherent limitations such as its mild laxative properties and the presence of cyanogenic glycosides, which may restrict its direct consumption. However, despite these constraints, linseed possesses substantial untapped potential as a functional and nutraceutical ingredient. The existing literature indicates that its health-promoting properties and diverse dietary applications remain relatively underexplored, thereby necessitating increased scientific investigation and greater consumer awareness.

A major strength of linseed lies in its rich profile of biologically active constituents, particularly α-linolenic acid (ALA), lignans (especially secoisolariciresinol diglucoside, SDG), and dietary fibre. These compounds contribute significantly to its physiological benefits, including antioxidant, anti-inflammatory, and cardioprotective effects. Advances in the identification and characterization of these bioactive components have enhanced the understanding of linseed's therapeutic potential, especially in reducing cardiovascular risk factors, preventing certain cancers, and regulating immune and inflammatory responses.

Evidence from experimental and clinical studies further substantiates the medicinal and disease-preventive potential of linseed and its derivatives. Such findings have facilitated the development of a variety of value-added and health-oriented food products incorporating linseed in multiple forms, including whole seeds, oil, and flour. The presence of essential nutrients and functional compounds has attracted considerable attention from food technologists, promoting its application in the formulation of commercially viable functional foods.

In addition, linseed has demonstrated remarkable versatility in its incorporation into diverse food systems, such as bakery products, dairy formulations, traditional foods, and ready-to-eat functional snacks. At optimal inclusion levels, it enhances the nutritional profile of these products without significantly compromising their sensory acceptability. This adaptability further strengthens its potential as a key ingredient in functional food development aimed at improving public health.

In conclusion, linseed represents a promising functional food resource with significant health and industrial relevance. Its wider integration into daily diets and food processing sectors can contribute to improved nutritional security and disease prevention. Therefore, continued research focusing on processing optimization, safety enhancement, and product development is essential to fully exploit its benefits. A daily intake of 1–3 tablespoons of ground linseed or approximately 1 tablespoon of linseed oil is generally recommended to harness its health-promoting effects effectively.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this review.

Data Availability

All relevant data supporting the findings of this study are included within the article. Additional information or supplementary data can be obtained from the corresponding author upon reasonable request.

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