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REVIEW ARTICLE

Comprehensive Overview of the Nutritional and Pharmacotherapeutic Properties of Flax Seeds (*Alsi*)

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Abstract

One of the most significant oil crops in the world, flaxseed (*Linum usitatissimum* L.), is grown worldwide in various countries. Flaxseeds are incredibly nutritious and include various necessary elements for good health. It is one of the highest sources of dietary lignan, secoisolariciresinol diglucoside (SDG), fibre, protein, and omega-3 fatty acids. It is a "superfood" widely accepted as vitamins, proteins, peptides, minerals, lipids, lignans, carbohydrates, and dietary fibre. Flaxseed has many pharmacological activities, including cardioprotective, neuroprotective, gastroprotective effects, anti-cancerous, antidiabetic, and other effects. Due to its high concentrations of Omega-3 fatty acids and free radical scavengers, flaxseed possesses impressive antioxidant and anti-inflammatory capabilities. The advantages of flax seeds in the healthcare, pharmaceutical, and food industries have been the subject of studies conducted worldwide. The current review covers Flaxseed's chemical makeup, nutritional benefits, and pharmacotherapeutic activities in depth. The studies of evidence suggest that flaxseed, in various forms and formulations, offers significant promise for disease prevention and health promotion across multiple systems.

KeyWords: Asli, Biological Activity, Flaxseed, Nutrition

1. Introduction

Flaxseed (*Linum usitatissimum* L.) is one of the world's best oil crops, mainly grown in Canada, India, Argentina, the United States, and China[1]. The species name for flaxseed, usitatissimum, comes from a Latin root meaning "most useful" or "profitable". It is an annual plant of the Linaceae family and is commercially grown in over 30 countries around the world[2]. Canada is the largest producer, with nearly 80% of the overall trade in flaxseed[3,4]. India ranks third in the world in production, accounting for about 10.2% of global output and first among the top flaxseed producers with about 23.8% of total planted area. It is mainly grown in the Indian states of Madhya Pradesh, Maharashtra, Chhattisgarh and Bihar[5].

Linseed and flaxseed are two terms that can be used interchangeably. It is commonly called Alsi in the Indian language due to its high oil content (35–40 %) and protein content (20–25 %); it has been used for fibre and seed for many generations[6,7]. Alpha-linolenic acid (ALA), which makes up the majority of the dietary omega-3 fatty acids in flaxseed, is also a plentiful source of fibre, protein, and lignan, mainly secoisolariciresinol diglucoside (SDG)[8].

Alpha-Linolenic Acid (ALA), lignan, and fibre are all found in high proportions in flaxseed, which is why it is becoming a vital component of functional foods. Dairy foods, dried pasta, and baked goods all use flaxseed. In addition to soluble dietary fibre, flax seeds contain vitamins A, C, E, and B6 and macro- and microelements (Na, Mg, P, and Zn)[9,10].

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Nutritionists worldwide recommend incorporating omega-3 fatty acids into one's diet. Flaxseed is the finest source of omega-3 fatty acids for people who do not eat seafood. Among the products made from flaxseed are edible whole flaxseed, ground meal, extracted oil, and mucilage. These products were created to be added to various foods as nutritional supplements, including muffins, bread, fibre bars, ready-to-eat cereals, salad toppings, spaghetti and baked cereal products[11].

There is a focus on the benefits of lignan phytoestrogens and omega-3-FAs in flaxseed for treating various medical issues. Due to the potential health advantages of numerous physiologically active components, including lignan (SDG), ALA and dietary fibres, flaxseed is becoming more popular among nutritionists and researchers in diet and disease analysis[12,13].

2. Nutritional Profile of Flaxseeds

Linseeds are a good source of a wide range of chemical components from the perspective of human nutrition (Summarised in Figure 1). It is known as a "superfood" which is well recognised as a nutritious source of proteins, minerals, vitamins and peptides, lipids (particularly polyunsaturated omega-3 and omega-6 fatty acids), carbs, dietary fibre and lignans[14-17]. Approximately 40% are fat, of which 15% are ω-6 fatty acids, and over 60% are ω-3 fatty acids. They include vitamin E, a naturally occurring antioxidant that protects the body's cells from the damaging effects of free radicals and about 28% fibre, both of which are essential nutrients. Additionally, flaxseeds have a 3-8% mineral content[18-20].

Flaxseed has 32-45 % oil by weight, including 51-55 % ALA and 15-18 % linoleic acid[21,22]. Alpha-linolenic acid is a precursor to the many important fatty acids found in the human diet. With minor amounts of pinoresinol, matairesinol, lariciresinol, and isolariciresinol, secoisolariciresinol diglycoside (SDG) is the main lignan in flaxseed[23-25]**.** Linseeds contain 30 to 40 per cent fatty acids, including high omega-3 fatty acids. In addition, headecenoic, hexadecanoic, and octadecanoic acids are found. Crystalline wax and a water-soluble resinous material are also found in trace amounts in oil. Leucine, arginine, glycine, glutamic acid and aspartic acid are all abundant in flaxseed protein, but tryptophan is scarce. The protein composition of flaxseeds ranges from 20 to 30%, with 80% of the protein being globulins (linin and conlinin) and 20% being gluten. The following essential amino acids are found in linseed total proteins: arginine, phenylalanine, lysine, histidine, tryptophan, threonine, methionine, valine, leucine, and isoleucine[26,27]. Linseeds are high in both soluble and insoluble dietary fibre. Mucilage gum is the most soluble fibre. The main carbohydrates in linseed are cellulose, mucilage, and sugars, including sucrose and raffinose. These polysaccharides undergo acid hydrolysis to produce L-arabinose, L-galactose, D-xylose, D-galacturonic acid, L-rhamnose and possibly remnants of D-glucose. Water has strong foam stability and can be used to dissolve mucilage[28].

Flaxseed has reported a wide range of pharmacological activity, such as cardioprotective, neuroprotective, gastroprotective, anti-cancer, antidiabetic, anti-inflammatory, antioxidant, antipyretic, anticoagulant, antihyperlipidemic, hormonal, and other properties[29].

Flaxseed has powerful antioxidant and anti-inflammatory properties due to its high levels of Omega-3 fatty acids and free radical scavengers[30,31]. Flaxseed also contains vitamin E, which has anti-carcinogenic and anti-oxidative properties and protects cell components from the detrimental effects of free radicals, which can contribute to the development of cancer[32,33].

3. Pharmacotherapeutic Activities of Flaxseeds

Flaxseed has reported a wide range of pharmacological activity (summarised in Table 1).

3.1 Antioxidant

Some studies have found that flaxseed has considerable antioxidant qualities due to its high quantities of free radical scavengers[34]. It has been shown that omega-3 fatty acids prevent neutrophils and monocytes from producing oxygen-free radicals, interleukin-1, tumour necrosis factor, and leukotriene B4 (LTB4)[35]. To prevent neutrophils from producing oxygen-free radicals, lignans may operate as platelet-activating factor receptor antagonists[36]. Antioxidants are abundant in flaxseed, especially lignans, which are polyphenols linked to the insoluble flaxseed fibre. Antioxidants



Figure 1. Nutritional profile of Flaxseeds per 100 grams (*Linum usitatissimum* L.).

included in food, such as lignan, aid in lessening the free radical damage caused by a variety of illnesses and ailments[37,38].

3.2 Neuroprotective

Flaxseed is a good source of omega-3 fatty acids, lignan phytoestrogens, and soluble fibres. Lignan has been shown to provide neuroprotective and antioxidant effects against neurodegenerative diseases such as spinal cord injury. As per one previous research, Flaxseed Oil (FSO) has a neuroprotective effect against CCl4-induced brain injury in gamma-irradiated rats[39]. In another work, pretreatment with Flaxseed oil showed neuroprotective effects on neurons of the motor cortex area and raised the functional motor recovery following the cerebral I/R injury by enhancing the levels of neurotrophic factors (BDNF and GDNF). This effect is linked to the ability of flaxseed oil to scavenge the free radicals, boost antioxidant enzyme activity, enhance glutathione levels and suppress the inflammatory responses[40,41].

Flaxseed oil and flaxseed flour are found to possess some antidepressant activity in rats exposed to chronic stress. Flaxseed consumption may enhance certain elements of brain function in cases of neural illness. A constituent of flaxseed, such as SDG, can increase the struggling time and normalise BDNF expression in ovariectomized mice exposed to chronic stress[42,43]. Flaxseed oil is also very beneficial for both shivering and nerve diseases like Alzheimer's disease and Parkinson's. In the Parkinson's disease reserpine antagonism model, omega-3 fatty acids stop neuronal cell death[44,45].

3.3 Cardioprotective Effect

In research on humans, flaxseed has been found to increase serum levels of the omega-3 fatty acids ALA and eicosapentaenoic acid and decrease levels of blood total cholesterol and low-density lipoprotein. It has also been demonstrated to decrease postprandial glucose absorption and certain indications of oedema. A naturally occurring source of long-chain fatty acids with cardioprotective qualities is alpha-linolenic acid. Linseed oil can be used to treat cardiovascular illnesses since it improves rats' ECG patterns and biochemical enzyme profiles, according to past research[46,47].

According to the study's findings from the Nutritional Examination Survey and National Health, those who consume enough fibre have a reduced risk of Peripheral Artery Disease (PAD). Alpha-Linolenic Acid (ALA), a kind of omega-3 fatty acid, is found in large

amounts in flaxseed. It also includes lignans, which are strong antioxidants. Therefore, it is likely that including flaxseed in the diet will lessen the risk of claudication and cardiac arrhythmias in patients with PAD. After a year of adding flaxseed to the diet, there were 2% fewer cardiac arrhythmias in the flaxseed group[48].

3.4 Atherosclerosis

Dietary flaxseed has shown significant preventive effects in adults with cardiovascular disease symptoms[49]. Flaxseed also contains lignan secoisolariciresinol diglucoside (SDG), a powerful antioxidant[50]. According to a study's findings, linseed SDG can prevent hypercholesterolemic atherosclerosis by elevating HDL-C levels in the blood and reducing oxidative stress. SDG may, therefore, help prevent hypercholesterolemic atherosclerosis and reduce the relative chance of developing Coronary Artery Disease (CAD)[51]. According to studies, switching from saturated to Polyunsaturated Fatty Acids (PUFAs) in the diet reduces the risk of Coronary Artery Disease (CAD). Flaxseed is effective at reducing hypercholesterolemic atherosclerosis without lowering blood cholesterol. Serum LDL cholesterol and total cholesterol levels were both high. Flaxseed's antiatherogenic effect is attributed to its a-linolenic acid concentration. The ability of flaxseed to decrease cholesterol may be a key mechanism for the antiatherogenic effects of flaxseed consumption that have been observed in animal studies. Flaxseed consumption prevented the onset of atherosclerosis in mice and rabbits fed an atherogenic diet. Although flaxseed did not reduce blood cholesterol levels in rabbits, it also reduced atherogenesis[52-54].

3.5 Hypertension

It has been suggested that flaxseed can lower elevated blood pressure. ALA and lignan of flax seeds lower the blood pressure and act as antihypertensive agents by blocking the Renin-Angiotensin System (RAS). Investigations into the mechanisms behind flaxseed oil's antihypertensive and renoprotective characteristics focused on sympathetic nerve activity, kidney and brain inflammation, and renal Angiotensin-Converting Enzyme (ACE) activity[55,56]. At a dose of 30 g per day, flaxseed powder was found to have antihypertensive effects in a clinical experiment. In DOCA-salt rats, ALA plays an important part in flaxseed's antihypertensive effects. One of the mechanisms of flaxseed's antihypertensive effects is assumed to be the inhibition of the hyperactive sympathetic nervous system. Along with the effects in the developed phase, this activity may contribute to the suppressive effects of DOCA-salt therapy on the onset of hypertension[57,58]. Random control trials in 5 trials involving 1302 participants demonstrated substantial drops in both SBP and DBP after supplementation with various flaxseed preparations, according to a meta-analysis research[59].

3.6 Dyslipidemia

Dyslipidemia is associated with an increased risk of atherosclerosis and heart disease, ultimaTely responsible for millions of deaths worldwide. Flaxseed improves the lipid profile. The current meta-analysis of 62 randomised studies found that adding flaxseed to one's diet reduced blood levels of LDL-C, TC and TG. Because flaxseed is high in fibre, it can help prevent dyslipidemia by increasing satiety, lowering caloric intake, and shortening food transit time. It also promotes bile acid excretion and inhibits bile acid reabsorption by increasing cholesterol excretion in faeces. Lignans are also diphenolic compounds that can lower cholesterol. ALA is an essential fatty acid that can be metabolised by the body as long-chain omega-3 fatty acids. It also encourages cholesterol efflux from macrophages by inhibiting the activity of stearoyl-CoA desaturase-1, which is a crucial defence mechanism for lowering blood cholesterol levels. Hence, consuming flaxseed and its products has a positive impact on reducing TC, LDL-C, and TG in humans and may be a useful alternative therapy to manage dyslipidemia and CVD[60-62].

3.7 Hepatoprotective

Nonalcoholic steatohepatitis (NASH), which can lead to cirrhosis or hepatocellular cancer, is one of the correlated chronic liver disorders known as Nonalcoholic Fatty Liver Disease (NAFLD). These include increased fat deposits in hepatocytes (simple steatosis), portal and lobular inflammation, and fibrosis. Flaxseed contains lignans, a type of phenolic compound that may counterbalance free radicals and peroxides, thus offering hepatoprotective properties. Flaxseed enhanced the histology of the liver and stopped the development of hepatic fibrosis from NASH. Further

studies are proceeding regarding the benefit of flaxseed in NASH[63]. It has been demonstrated that defatted flaxseed significantly reduces triglycerides, Low-Density Lipoproteins (LDLs), and total cholesterol. Flaxseed oil pretreatment reduced the level of inflammatory markers of the liver, such as AST, ALT and acid phosphatase[64,65].

3.8 Renoprotective Effect

In rats with polycystic kidney disease, flaxseed improves citrate excretion and lessens histologic damage[66]. Flaxseed consumption also reduced proteinuria and glomerular and tubulointerstitial lesions in an obese SHR/N-cp rat model. Antioxidant activity of flaxseed oils also ameliorated the thioacetamide-induced renal injury[67,68]. The flaxseed oils also exhibited protective effects in ameliorating renal injuries linked with hypercholesterolaemia[69].

3.9 Antidiabetic

The most prevalent DM consequence, Diabetic Neuropathy (DN), affects about 50% of diabetic patients and is associated with shrinkage, demyelination of nerve axons, and a high mortality rate. The primary flaxseed oils containing lignanes and secoisolariciresinol neutralise free radicals and regulate the incidence of DM and undesirable future results[70]. Supplemental flaxseed lowered blood sugar levels in people with type 2 diabetes and in people with prediabetes. In participants with Type 2 diabetes, lignan supplementation and gum made from flaxseed also reduced blood sugar levels. The flaxseed lignan SDG has been shown in pre-clinical investigations to have anti-hyperglycemic actions in animals. Meals containing flaxseed and postprandial hyperglycemia were decreased by 27% in the case series[71-73]. Flaxseed lignan SDG has been discovered to inhibit the phosphoenolpyruvate carboxykinase gene, which codes for a significant enzyme involved in the synthesis of glucose in the liver[74].

3.10 Metabolic Syndrome

MS is a complex condition with a steadily rising incidence. It is a collection of risk factors that may be treated extremely complexly[75], including obesity, glucose intolerance, dyslipidemia, and insulin resistance. However, research using both human and animal models shows that a higher consumption of flaxseed or its separated lignans is negatively correlated with the prevalence of MS symptoms. In one study, it was shown that giving MS patients golden flaxseed supplements for 28 days improved their biochemical, anthropometric, and oxidative markers as well as their blood pressure. In both control subjects and MS patients, flaxseed supplementation for 28 days resulted in significant decreases in triacylglycerol, fasting glucose, LDL cholesterol, total cholesterol, LDH, CK, CK-MB, creatinine, BUN, AST, uric acid, and ALT levels and a significant increase in HDL cholesterol levels[76]. Hesperidin and flaxseed co-administration reduced three of the five MS risk factors, including systolic blood pressure, hyperglycemia, and serum triglycerides. The individual benefits of flaxseed, however, outweigh hesperidin supplementation by themselves[77].

3.11 Gastroprotective Effect

Ulcerative colitis and Crohn's Disease are chronic inflammatory bowel diseases that are not fully curable and usually cause progressive weakness. It has been demonstrated that flaxseed is advantageous for those with Crohn's disease and ulcerative colitis. Even for people with normal digestive function, dietary fibre supports healthy gut flora[78]. Flaxseed is a well-known all-natural treatment for constipation because of its high soluble and insoluble fibre content. It serves as a dietary supplement to maintain regular bowel movements. Long-term flaxseed oil consumption reduced the clinical symptoms of colitis in rats and partially reversed DSS-induced changes in gut flora[79]. A study discovered that flaxseed oil and mucilage greatly reduced the likelihood of ethanol-induced stomach ulcers. The findings demonstrated 28 that pretreatment with flaxseed oil and mucilage greatly decreased the number and duration of stomach ulcers brought on by ethanol in rats[80]. Furthermore, flaxseed has long been used to treat inflammatory bowel disease IBD. Flaxseed oil's antidiarrheal effects may be attributed to Ca^{2+} channel inhibition and non-specific K^{+} channel activation[81,82]. Previous research has shown that the antioxidant and anti-inflammatory characteristics of flaxseed extract rendered it useful in treating mice with 6% Acetic acid-induced colitis[83,84].

3.12 Antineoplastic

Flaxseed may also assist in lowering the risks connected to specific cancers, such as those of the colon, prostate, ovaries, and breast. In terms of the effects of dietary flaxseed, breast cancer has arguably been the subject

of the most research. It has been hypothesised that the abundance of SDG and ALA in flaxseed contributes to its protective effects against cancer. It has been shown that consuming flaxseed has been shown to suppresses the proliferation and nuclear transformation of epithelial cells in the mammary glands, and diets containing these substances have been linked to a lower risk of cancer growth[85,86]. A 2% omega-6 fatty acid (ALA) formulation has been shown in rat experiments to diminish tumour size in mice[87]. Along with having estrogenic properties, flaxseed can disrupt the absorption and metabolism of steroids. It can also block enzymes like tyrosine kinase and topoisomerase, which are essential for cellular proliferation and may help reduce the risk of prostatic adenocarcinoma. The second most frequent cancer in women is ovarian cancer, which continues to have the greatest fatality rates. Flaxseed consumption reduces the risk of ovarian cancer[88,89]. On the cell lines MCF-7 and HCT, the ethanolic flaxseed extract has been reported to have a significant cytotoxic effect. Furthermore, roasted defatted flaxseed showed a significant anticancer effect against two tested cell lines, particularly MCF-7 cell line. While defatted flaxseed revealed anticancer activity against the (HCT) cell line compared to the (MCF-7) cell line[90,91].

3.13 Antimicrobial

Salmonella typhii, *Bacillus subtilis*, Enterococcus, *Staphylococcus aureus* and *Escherichia coli* were the important bacteria used in the trial investigation to determine the antimicrobial activity of ethanol and chloroform extracts of flaxseeds. The outcome shows that ethanol extract is less effective against bacteria than chloroform extract. The bacteria were all susceptible to the antibiotic effects of chloroform extracts[92]. An aqueous methanol extract (80% v/v) of flax seeds is also effective against Staphylococcus aureus and Escherichia coli[93]. Another study looked at the potential of crude, aqueous, and methanolic flaxseed extracts to inhibit the growth of four multi-resistant bacteria, including *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*[94]. The antimicrobial activity of SDG (an important lignan found in flaxseed) extracts of flaxseed was also evaluated against the six bacterial species: *Staphylococcus aureus*, *Agrobacterium tumefaciens*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Bacillus subtilis*, and *Escherichia coli*[95].

3.14 Anti-inflammatory, Analgesic and Antipyretic

Flaxseed oil has been reported to inhibit Carageenan-induced inflammation (Paw oedema) in Wistar rats[96]. Major lignans Secoisolariciresinol diglucoside can be isolated and purified from Indian flaxseed, which synergistically with sesamin inhibit the pro-inflammatory mediators such as 15-LOX and COX-2 *in vitro*. *In vitro*, SDG administration reduced the expression of pro-inflammatory factors such as Inducible Nitric Oxide Synthase (INOS), cyclooxygenase-2 (COX2), Tumour Necrosis Factor (TNF), and interleukin 6 (IL-6)[97,98]. In one study, anti-inflammatory, analgesic and antipyretic activity was evaluated in different animal models. The analgesic efficacy of flaxseed oils was tested in mice utilising tail immersion and acetic acid-induced writhing paradigms. The anti-inflammatory effect of carrageenan and prostaglandins was tested in rats using a paw oedema model generated by prostaglandins. The antipyretic activity was assessed in rats using a typhoid-paratyphoid vaccine-induced pyrexia model[99].

3.15 Miscellaneous Effect

Other pharmacological effects of flaxseed include lowering obesity-related inflammation. Additionally, it has been proposed that flaxseed and its lignans have potent antiestrogenic effects on oestrogen receptor-positive breast cancer. Additionally, the activity of aromatase, 5-alpha-reductase, and 17-beta-hydroxysteroid dehydrogenase is inhibited by these substances. In addition, it has been discovered that lignans encourage the production of sex hormone-binding globulin[100].

Linseeds increase hair length while having a somewhat positive impact on hair diameter. Consumption of linseed increases hair density. The most prevalent type of arthritis among rheumatic disorders is osteoarthritis (OA). The flaxseed plant contains large amounts of omega-3 fatty acids and alpha-linolenic acid, which inhibit arachidonic acid and halt neutrophil inflammatory response. Thus, flaxseed reduces the production of prostaglandins and leukotrienes[101]. The use of a flaxseed supplement similarly reduced the thrombin-induced platelet aggregation[102]. Flaxseed may have laxative effects by raising faecal volume and causing peristalsis due to stretch reflexes in the faeces. There is proof to back up the claim that flaxseed protects and coats the gastrointestinal mucosa. Administration

of flaxseed flour (10g powder with honey) can help with stomach ulcers, hemoptysis, splenomegaly, and pulmonary TB[103]. Flaxseed oil consumption improved several skin features in a 12-week, randomised, double-blinded experiment on healthy female volunteers with sensitive skin[104]. Consumption of flaxseed as a dietary supplement has been shown to balance pro- and anti-inflammatory oxylipins, which may slow the ageing process[105]. Cyclonolinopeptide-A, which has strong immunosuppressive and antimalarial characteristics and suppresses the human malaria parasite *Plasmodium falciparum* in culture, is one of the bioactive peptides found in flaxseed[106].

4. Marketed Formulations of Flaxseed

Flaxseed is commercially available in a wide range of formulations designed to deliver its rich profile of omega-3 fatty acids, lignans, dietary fibre, and other bioactive components, as shown in Table 2. These

Table 1. Pharmacotherapeutic activities of flaxseeds

Pharmacological activity	Flaxseed portion	Key Phytocompounds in Flaxseed	*In vitro* / Animal models	Affecting parameters	References
Antioxidant	Germinated flaxseeds, Grounded Flaxseed	Lignans (Secoisolariciresinol diglucoside — SDG), Flavonoids, Polyphenols	*In vitro* Wistar albino rats	DPPH and ABTS free radical scavenging activity. Malondialdehyde (MDA), Oxidative Stress Index (OSI), total thiols (SH), Total Oxidative Status (TOS), and Total Antioxidant Reactivity (TAR)	34, 37
Neuroprotective	Flaxseed oil Flaxseed oil Flax lignan	Alpha-Linolenic Acid (ALA), Lignans (SDG), Polyphenols	CCl4-induced brain injury rats. Spinal Cord Injury (SCI) in rats. NMDA-Induced Neurotoxicity *In Vitro*	Decreased tissue degeneration and improved locomotor function. Reduced oxidative stress level. ↑SOD, CAT, GPx and ↓ MDA levels in the brain. Downregulating GluN2B expression level. Regulating Bcl-2 family	39, 40, 107
Anti-Parkinson	Flaxseed oil	Alpha-Linolenic Acid (ALA), Lignans (SDG), Polyphenols	Mice	Weight loss and neural abnormalities linked to rotenone-induced Parkinson's disease	44
Cardioprotective	Flaxseed oil	Omega-3 Fatty Acids (ALA), SDG, Fibre	Isoproterenol-induced myocardial infarction in rats	Reduced the activity of every cardiac enzyme, including AST, CK-MB, ALT, LDH, and ALP.	46
Anti-atherosclerotic	Flaxseed (7.5 g/kg daily, orally)		Rabbit	Reduced Aortic atherosclerosis (46%) by reducing oxygen free radicals and polymorphonuclear leukocytes (PMNLs)	53, 54
Dyslipidemia	Flaxseed and its components (flax oil, flax fibres)	SDG, lignan complex,	Rats, rabbits, and Humans	Decreased TC, TG and LDL-C blood levels in a dose-dependent manner	60
Hypertension	Flaxseed and its components	ALA, lignans (such as secoisolariciresinol diglucoside or SDG), Potassium and Magnesium	Rats, Rabbits Humans	Reduce the diastolic and systolic pressures; however, most research indicates that the pressure drop is not significant.	55, 57

Table 1. Continued...

Pharmacological activity	Flaxseed portion	Key Phytocompounds in Flaxseed	*In vitro* / Animal models	Affecting parameters	References
Antimicrobial	Ethanol and chloroform extract of flaxseed	Lignans, Phenolic acids, Peptides	*In vitro* antimicrobial assay using Salmonella typhi, Enterococcus, Escherichia coli, Bacillus subtilis, Staphylococcus aureus	↑ Inhibition zone	93,94,95
Metabolic syndrome	Golden flax seeds	SDG, Polyphenols, ALA	Patients with MS and 24 healthy Volunteers (Humans)	Decreased levels of triacylglycerol, total cholesterol, LDL cholesterol, and fasting glucose; increased levels of HDL.	76
Antidiabetic	Meals containing flaxseed	SDG, Fibre, Omega-3 Fatty Acids	Animals and humans	Postprandial hyperglycemia decreased	71,72,73
Anticancer	Roasted defatted flaxseed Defatted flaxseed	Lignans (SDG → enterolactone and enterodiol), Omega-3 Fatty Acids, Polyphenols	*In vitro* cytotoxicity against colon and breast carcinoma cell lines	↑ Percent inhibition	90,91
Hepatoprotective	Flaxseed oil Flaxseed extract	SDG, Polyphenols, Omega-3 Fatty Acids	Radiation-induced Hepatotoxicity in Mice Wistar rats	Decreased AST, lipid peroxidation (LPO), ALT and acid phosphatase in Flax seed-treated irradiated mice. Decrease the levels of TC, TG, VLDL, and LDL and increase the HDL level. Improved the Serum level of SGOT, SGPT, and ALP enzymes, which are the biomarkers used to monitor the structural integrity of the liver.	64, 65
Anti-inflammatory	Flaxseed oil	Lignans (SDG), Omega-3 Fatty Acids (*α-linolenic acid* - ALA)	Carrageenan and PGE2-induced paw oedema in rats.	Reduced paw oedema in rats	96,99
Analgesics and antipyretics	Flaxseed oil	ALA, lignans (SDG), and polyphenols	Acetic acid induced writhing pain and the Tail immersion test in Swiss albino mice for analgesia. Typhoid paratyphoid vaccine induced pyrexia in Wistar rats.	Increase pain threshold in mice. Reduced body temperature in rats	99, 106

Table 2. Marketed formulations of flaxseed

Formulation Type	Use / Description	Examples
Flaxseed Oil Capsules	Rich in omega-3 (ALA); used for heart health, anti-inflammatory effects	NOW® Flax Oil, Himalaya Wellness Flaxseed Oil
Ground Flaxseed Powder	Full-fat or defatted powder; added to foods for fibre, lignans, and omega-3s	Bob's Red Mill® Flaxseed Meal, 24 Mantra Organic, Satvyk® Organic Flax Powder
Flaxseed Lignan Extract	Rich in SDG; used for antioxidant support, hormonal balance, and menopause support.	Jarrow Formulas® Lignan Extract, FlaxLignan™ SDG Extract
Flaxseed Oil Softgels (Vegan)	Plant-based omega-3 supplements are suitable for vegetarians and vegans	Solgar® Flaxseed Oil, Nutrigold® Flaxseed Oil Softgels
Flaxseed in Functional Foods	Incorporated into cereals, bars, and beverages for nutrition enhancement	Kind® Bars with Flax, Kellogg's® cereals with flax, Good Karma® Flaxmilk
Topical Cosmetic Formulations	Used in creams/oils for skin nourishment due to antioxidant and omega-3 content	Organic flaxseed carrier oils, massage oils, and base oils

formulations are used as dietary supplements to support heart health, reduce inflammation, and promote joint function, hormonal balance, and antioxidant support. Also, as functional foods, such as protein bars, cereals, and plant-based beverages, are easy to incorporate into the diet. Some cosmetic and topical formulations include flaxseed oil for its skin-nourishing and anti-inflammatory properties.

5. Precautions for the Usage of Flaxseed

Flaxseed offers numerous health benefits, but should be used with caution. Firstly, flaxseed should preferably be consumed in its ground or milled form rather than whole, as whole seeds may pass through the digestive system undigested, reducing nutrient absorption. Due to its high fibre content, excessive intake can lead to bloating, gas, or diarrhoea, especially if water intake is insufficient. People on blood thinners and antihypertensive medications should be cautious, as flaxseed's omega-3 content may have mild blood-thinning and blood pressure-lowering effects[107].

6. Conclusion

The research results established the nutritional and therapeutic value of flaxseeds, which are also used as food in many parts of the world. Flaxseeds are incredibly nutritious and include various necessary elements for good health, according to an examination of their nutritional makeup. The flaxseeds also possess nutritional and therapeutic importance. The flaxseeds are essential for supplying micronutrients and are also used to treat and control conditions, including diabetes, inflammation, hyperlipidemia, hypertension, and cancer, as well as to protect the heart. For people to include these in their daily meals, more research and education on their nutritional and therapeutic benefits are needed.

7. Author Contribution

Conceptualization: [RK, SP], Literature Search and Data Collection: [AM, TP], Writing Original Draft Preparation: [AN, GGF)], Writing – Review & Editing: [RK, SP, MP], Supervision: [RK, MP], Visualization (figures/tables): [AM, GGF]. All authors have read and agreed to the published version of the manuscript.

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