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Role of flaxseed (*Linum usitatissimum* L.) in disease prevention and treatmentC Manimurugan¹, M. Sujatha¹, A. L. Rathnakumar¹, M Sandhanalakshmi², Anand A. Zanwar³✉¹ICAR–Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad–500030, India²Central Leprosy Teaching and Research Institute, Chengalpattu–603001, India³Interactive Research School for Health Affairs, Bharati Vidyapeeth (Deemed to be University), Pune–411043, India

ABSTRACT

Seeds of flax or linseed (*Linum usitatissimum* L.) are important nutraceutical foods with antioxidant, anti-inflammatory, estrogenic, laxative, and antibacterial properties. Flaxseed oil and seeds are the richest vegetarian source of omega-3 fatty acids. Consumption of flaxseeds helps in prevention and control of cardiovascular disease, neurodegenerative disorders, obesity, diabetes mellitus, polycystic ovary syndrome, gout, liver and kidney dysfunction, oxidative stress-related diseases, post-menopausal symptoms, osteoporosis, irritable bowel syndrome, dry eye disease, cystic fibrosis, diarrhea, and cancer, particularly of the mammary and prostate gland cancer. Of late, flaxseed is gaining more importance not only because of its industrial values but also due to its nutraceutical and pharmaceutical properties. The literature review was performed using PubMed, Scopus, PubMed Central, Google Scholar, and Web of Science from 1995 onwards. Data was also obtained from websites/books/book chapters.

KEYWORDS: Flaxseed; *Linum usitatissimum*; Omega-3 fatty acid; Preventive medicine; Nutraceutical foods

1. Introduction

Flax is one of the ancient cultivated crops. It is mainly cultivated all over the world for its oil, fiber, and seed. The Latin name of flaxseed is "*Linum usitatissimum* L.", which means "very useful". Every part of the flaxseed plant has industrial importance. The important bioactives in flaxseed are α -linolenic acid (ALA), lignan, protein, dietary fiber, and minerals. Flaxseed contains a very limited amount of carbohydrates (approximately 1%), 33%-47% of oil/fat, and 21% of protein[1]. Flaxseed oil consists of 53% of ALA, 17% linoleic acid (LA), and 19% oleic acid[2,3]. The protein in flaxseed has an 89.6% coefficient of digestibility and 77.4% biological value[4]. Flaxseeds

are a good source of sulfur-containing (methionine and cysteine) and branched-chain amino acids (isoleucine, leucine, and valine). It is also comprised of limiting amino acids like lysine, threonine, and tyrosine. Additionally, flaxseed is also a good source of various kinds of phenolic acids such as ferulic acid (10.9 mg/g), chlorogenic acid (7.5 mg/g), gallic acid (2.8 mg/g) along with some minor phenolic acids such as *p*-coumaric acid glucosides, hydroxycinnamic acid glucosides and 4-hydroxybenzoic acid[3]. These phenolics play an important role in prevention and inhibition of the progression of cancer and also possess anti-oxidative properties[5]. The most important bi-phenolic compound present in flaxseed is lignan [secoisolariciresinol diglucoside (SDG: 294-700 mg/100 g), pinoresinol (3.32 mg/100 g), matairesinol (0.55 mg/100 g) and lariciresinol (3.04 mg/100 g)]. Among these, SDG is well studied and a therapeutically bioactive lignan present in flaxseed[6,7]. Flaxseeds are also rich in minerals like calcium (236 mg/100 g), magnesium (431 mg/100 g), phosphorus (622 mg/100 g), and potassium (831 mg/100 g); vitamins like γ -tocopherol (522 mg/100 g), α -tocopherol (7 mg/100 g), δ -tocopherol (10 mg/100 g) and niacin (3.2 mg/100 g)[3]. In the current scenario, omega-3 fatty acid is an essential and nutritionally important fatty acid and along with vitamins and minerals in flaxseed made it a 'super food'. Though flaxseed has many medicinal properties, it is very important to know the beneficial

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effects and side effects of flaxseed before its consumption. In this review, studies done on flaxseed consumption methods, nutritional facts, and their important role in human health are briefly presented.

2. Flaxseed consumption

Flaxseeds are consumed as sprouted, roasted, ground, and in the form of oil after extraction. The seeds are usually brown or yellow, flat, and oval in shape with a pointed end. It consists of a seed coat, thin endosperm, embryo, and embryonic axis[8]. The seeds possess a pleasant nutty taste with a crisp and chewy texture[9]. Differences are not found in the nutritional status of brown and yellow varieties of flaxseed[10]. Generally, consumption of one to two tablespoon of ground flaxseed is recommended per day for a healthy person[11]. The bioavailability of nutrients is improved only after processing flax seeds. Bread, pasta, egg products, ready-to-eat snacks, energy and fiber bars, salad, and spaghetti can be enriched with flax seeds[2,12]. About 20% to 25% of daily fiber needs can be fulfilled by consuming half an ounce of dry whole flax seeds and 30 g of flaxseeds contain 7% to 30% of the recommended dietary allowances of calcium, magnesium, and phosphorus[2]. When flaxseed is consumed, SDG lignan is metabolized in the gastrointestinal tract by intestinal bacteria to form enterolactone and enterodiol. These are secondary metabolites also called mammalian lignan. A higher concentration of mammalian lignan in the blood and urine is negatively correlated with major chronic disease. Enterolactone and enterodiol are known to have weak estrogenic activity[13]. Because of this, SDG is classified as phytoestrogens. Various preclinical studies on pure SDG lignan or lignan concentrate have shown a beneficial role in diabetes[14], antioxidant action[15,16], cholesterol-lowering property[17], cardio-protection[16,18], hypercholesterolemic menopause[19], hypertriglyceridemia, and reduction of atherogenic risks[14,20] and hyperlipidemia[21], etc.

3. Flaxseed in human health

Human diseases are caused by genetic, environmental, pathogenic, nutritional, food habits, and lifestyle reasons. Adding functional foods like nutrient-rich fruits, vegetables, nuts, seeds, and grains which have a potentially positive effect on health beyond basic nutrition in our food habits can prevent and postpone some diseases as well as contribute to the management of several kinds of diseases. Flaxseed is one of the functional foods which have huge health benefits. Table 1 summarizes the health benefits of flaxseed and its various components.

3.1. Cardiovascular and related complications

Long-term hypertension is more common and is a risk factor for heart disease, stroke, and kidney failure[22]. Consumption of flaxseed protein hydrolysate which contains a peptide mixture with high levels of branched-chain amino acids and low levels of aromatic amino acids inhibits the angiotensin-converting enzyme and thus reduces the blood pressure[23]. The anti-hypertensive property of flaxseed SDG lignan was investigated and the results showed that rats feeding with SDG lignan decreased the systolic, diastolic, and mean arterial blood pressure[24]. Vitamin E present in flaxseed promotes sodium excretion in the urine which may help in the lowering of blood pressure and reduce the risk of heart disease[25].

High-fat diets, sedentary lifestyles, and obesity lead to dyslipidemia, a condition in which increased levels of lipids (*e.g.*, triglycerides, cholesterol, and/or fat phospholipids) are present in the blood. A significant reduction in total cholesterol, triglycerides, low-density lipoprotein-cholesterol, and very low-density lipoprotein cholesterol levels was observed in the dyslipidemia experimental group when flaxseed was supplemented with their food[26]. A significant decrease in plasma triglyceride in both lean and obese rats after flaxseed meal supplementation suggested it as a new therapeutic strategy to reduce hypertriglyceridemia and fatty liver disease (a condition in which fat builds up in the liver)[27]. Intake of flaxseed fiber, rich in viscous dietary fibers, effectively lowered total and low-density lipoprotein cholesterol by increased fat excretion[28].

Rodriguez-Leyva *et al.* have reported the role of dietary supplementation with flaxseed as a potent intervention in hypertensive patients[29]. Consumption of flaxseed reduces the risk of atherosclerosis by lowering both total and low-density lipoprotein-cholesterol in blood circulation. Studies in animal models showed that supplementation of a cholesterol-enriched diet with ground flaxseed inhibits plaque formation in the aorta and aortic sinus[30].

Peripheral arterial disease is a common circulatory problem of medium and small-sized arteries where a build-up of fatty plaque narrowing the lumen of arteries occurs and reduces blood flow to limbs. Particularly, legs do not receive enough blood flow which causes ischemic pain (claudication) and make it difficult to walk a long distance. When flaxseeds are consumed, ALA present in flaxseed may alter plasma oxylipin concentration which produces antihypertensive effects in patients with peripheral arterial disease[31]. Mahmudiono *et al.* concluded the beneficial effect of flaxseed oil on systolic blood pressure in subjects with metabolic syndrome and related disorders[32]. Jiang *et al.* reported the effect of flaxseed oil on controlling serum insulin and highly sensitive C-reactive protein levels in type 2 diabetes mellitus patients with coronary heart disease[33]. Talari *et al.* evaluated co-supplementation of vitamin D and flax oil in diabetic patients with coronary heart disease in a randomized, double-blinded, placebo-controlled trial and

Table 1. Health beneficial effects of flaxseed in disease prevention and treatment.

Diseases	Parts of the flaxseed	Effect	References
Cardiovascular and related complications	Flaxseed protein hydrolysate	Reduces blood pressure by inhibiting the angiotensin-converting enzyme	[23]
	Flax lignan	Helps in controlling systolic, diastolic, and mean arterial blood pressure	[24]
	Flaxseed meal/cake and whole flaxseed	Controls hypertriglyceridemia, fatty liver disease as well as atherosclerosis (total and low-density lipoprotein-cholesterol)	[26–28,30]
	Flaxseed oil	Exerts antihypertensive effects in peripheral arterial disease, regulates systolic blood pressure in subjects with metabolic syndrome and controls serum insulin and highly sensitive C-reactive protein levels	[31–33]
Diabetes mellitus	Flaxseed	Improves insulin sensitivity in overweight/obese in pre-diabetic patients and glycemic control in pre-diabetic and type-2 diabetes mellitus patients	[35,42]
	Flaxseed meal/cake	Controls proteinuria and renal parenchymal abnormalities in type 2 diabetes	[36]
	Flaxseed oil	Improves inflammation, glycaemic control, inflammatory markers and oxidative stress in gestational diabetes mellitus, reduces inflammation and modulates gut microbiota in type 2 diabetes	[38,40]
	Flaxseed lignan	Controls glucose levels and lipid profile	[39]
Cancer	Flaxseed (lignan and oil)	Reduces the growth of tumors in breast cancer	[45]
	Flaxseed lignan	Effective in acute myeloid leukemia cancer cells	[49]
	Flaxseed oil	Inhibits osteosarcoma cell proliferation and metastasis	[51]
Photoreactive damage	Flax lignan and flax oil	Lignan improves survival after irradiation and flax oil prevents from photoreactive damage	[52,53]
Neurodegenerative disorders	Flaxseed protein hydrolysate	Reduces the production of nitric oxide, thereby reducing risk of neurodegenerative disorders	[55,57–59]
Polycystic ovary syndrome	Flaxseed	Improves metabolic biomarkers in polycystic ovary syndrome patients as well as metabolic, hormonal, and anthropometric functions in women with polycystic ovary syndrome	[62,64]
Gout and oxidative stress-related diseases	Flaxseed oil	Inhibitory effect on xanthine oxidase	[65]
Constipation	Flaxseed	Laxative action in irritable bowel syndrome	[66]
Dry eye disease	Flaxseed oil	Improves ocular surface disease index	[67]
Kidney disorder	Flaxseed oil	Protective effect on lead-induced kidney injury in <i>in vivo</i> study; Improves liver and kidney functions in hypertensive rats; Improves renal function and reduces glomerular injury; Reno-protective action in lupus nephritis	[69,71–73]
Liver disorder	Flaxseed cake or whole flaxseed powder and flax oil	Flaxseed improves non-alcoholic fatty liver disease and flax oil improves fatty liver and inflammation	[74–76]
Stomach ulcers	Flaxseed oil and mucilage	Cytoprotective effect on ethanol-induced gastric ulcers in rats	[79]
Cystic fibrosis	Flaxseed metabolites (enterolignans)	Significantly reduces the urinary oxidative stress	[80]
Infectious and non-infectious diarrhea	Methanolic extract of flaxseed	Bactericidal action	[81]
	Flaxseed oil and mucilage	Antidiarrheal and laxative potential	[82]

reported the beneficial effects on markers of cardiometabolic risk[34].

3.2. Diabetes mellitus

Daily consumption of flaxseed was found to be responsible for reduced glucose levels and improved insulin sensitivity in overweight/obese individuals with pre-diabetes[35]. It was also more effective in reducing proteinuria and renal parenchymal abnormalities in animal models of type II diabetes mellitus[36]. Thakur *et al.* reported the efficacy of flaxseed gum in type 2 diabetic patients by controlling blood sugar and lipid profile, especially total cholesterol and low-density lipoprotein cholesterol[37]. Omega-3 fatty acid supplementation (2 g/day) from flaxseed oil for 6 weeks to women with gestational diabetes mellitus had beneficial effects on gene expression related to insulin, lipid and inflammation, glycaemic control, inflammatory markers, and oxidative stress[38]. Draganescu *et al.* evaluated the effect of flaxseed lignans on streptozotocin-induced diabetic rats and revealed flaxseed lignans can control glucose levels and lipid profile and improve the impaired function of the organs in diabetic rats[39]. Further, dietary flax oil ameliorated type 2 diabetes by suppressing inflammation and modulating gut microbiota[40]. A systematic review and meta-analysis of 13 clinical studies revealed that supplementation of flaxseed to diabetic subjects significantly reduced hemoglobin A1c and the effect was more promising in patients having poor control over the sugar level[41]. A promising role of flaxseed in improving glycemic control variables and insulin resistance in both prediabetes and type-2 diabetes mellitus patients was also reported[42].

3.3. Cancer (Neoplasia)

Cancer is a disease caused by the uncontrolled growth of cells that is not under physiologic control in parts of the human body and it is the second leading cause of death in the world next to cardiovascular disease[43]. The SDG lignan present in flaxseed plays a vital role in cancer management. SDG lignan in flaxseed possesses a weak hormonal action and competes with the same receptor for estrogen. This may decrease the hormonal signaling involved at the beginning of tumor development in the breast[44]. Chronic consumption of flaxseed increased urinary 2 α -hydroxy estrone/16 α -hydroxy estrone ratio associated with a lower risk of breast cancer. Flaxseed intake also reduced the growth of tumors in breast cancer patients by decreasing cell proliferation and angiogenesis and increasing cell apoptosis[45]. Recent evidence showed that a combination of lignan or oil from flaxseed with tamoxifen (a standard chemotherapy drug) reduced the growth of tumors by decreasing cell proliferation and gene expression[46], suggesting the utilization of lignan as an adjuvant therapy in chemotherapy of breast cancer. Consuming lignans may reduce the risk of endometrial cancer in postmenopausal

women. A pilot study showed that a flaxseed-supplemented (30 g/day for 34 days), fat-restricted diet for 25 patients with prostate cancer reduced the cancer biomarkers like total serum cholesterol, total testosterone, and free androgen index[47]. Vitamin E present in flaxseed also reduces the risk of cancer by increasing the immune function and blocking the formation of carcinogenic nitrosamines in the stomach from nitrites in foods[48]. Flax lignan has an inhibitory effect on acute myeloid leukemia cancer cells[49]. ALA present in flaxseed plays a protective role in human breast cancer by inhibiting fatty acid synthase[50]. In the case of osteosarcoma treatment, ALA inhibits osteosarcoma cell proliferation and metastasis by suppressing the expression of fatty acid synthase[51].

3.4. Radioprotective activity

Radiotherapy is used in treating many types of cancer. Pulses of radiation are used to shrink or lysis the tumor cells. The effect of a flaxseed lignan-enriched diet was investigated in mice that are irradiated with a single fraction (13.5 Gy) of X-ray radiation treatment. Feeding mice 10% and 20% lignan complex of flaxseed displayed improved survival after irradiation by upregulation of protective antioxidant enzymes such as heme oxygenase-1 and NAD(P)H quinone oxidoreductase 1. This supports the protective role of lignan from flaxseed in radiation induced lung injury[52]. Dietary flaxseed oil protects from ultraviolet C-induced apoptosis due to antioxidant and antiapoptotic effects in an animal model, indicating a protective role in photoreactive damage. In this study, flaxseed oil (4 mL/kg bw) was given by gavage to rats and the effect of ultraviolet C irradiation was studied. Flaxseed oil reduced malondialdehyde and protein carbonyl and alleviated oxidative stress and apoptosis, indicating that it may be useful for preventing photoreactive damage[53].

3.5. Neurodegenerative disorders

The death of brain cells causes neurodegenerative disorders like Alzheimer's disease, Huntington's disease, Parkinson's disease, *etc.*, which are very difficult to be cured. Among many reasons, nitric oxide, an endogenously synthesized free radicals in the body, causes neuroinflammation and contributes to the development of Alzheimer's disease[54]. Flaxseed protein hydrolysate induced a change in secondary and tertiary structures of calmodulin which presumably decreases the production of nitric oxide and thus reduces the risk of neurodegenerative disorders[55]. Vitamin E and omega-3 fatty acids with antioxidant activity also reduce the risk of neurodegenerative disorders[56]. In a randomized controlled trial, supplementation of flaxseed (20 g/d) for 4 weeks was responsible for improved mental fatigue in obese children[57]. In addition, supplementation of flax oil (1 g/day) twice a day for 10 weeks

increased the level of serum BDNF and improved the depression status in depressed women[58]. Consumption of ALA (2.2 g/day) was found to improve cognition including verbal fluency in healthy older adults[59]. These clinical findings indicate a beneficial role of flaxseed in neurodegenerative disorders.

3.6. Polycystic ovary syndrome (PCOS)

PCOS is a cystic disorder of the ovary with an irregular menstrual cycle and is often associated with a high level of androgens. Normal menstruation and ovulation are suppressed by a slight increase in testosterone levels in a woman's body[60]. Intake of flaxseed lignans reduces the risk of PCOS in susceptible women as lignan binds with free circulating testosterone and is excreted by the biliary system. Flaxseed supplementation (30 g/day) for four months to a 31-year-old PCOS woman showed a reduction in total testosterone and free testosterone along with reduced hirsutism[61]. In a randomized, open-label, controlled clinical trial, supplementation of flaxseed powder (30 g/day) along with lifestyle modification improved the metabolic biomarkers in PCOS patients[62]. In a pre-clinical study, flax oil showed a beneficial effect on PCOS *via* the sex steroid hormones-gut/vaginal microbiota-inflammation axis in rats[63]. In another study, flaxseed supplementation improved metabolic, hormonal, and anthropometric functions in women with PCOS[64].

3.7. Gout and oxidative stress-related diseases

Gout is caused by hyperuricemia, a condition in which high levels of uric acid are present in the body. *In vitro* studies showed that flaxseed oil has an inhibitory effect on xanthine oxidase. But the effect was less significant when compared with a standard xanthine oxidase inhibitory drug Allopurinol. At the same time, flaxseed oil showed minimal side effects when compared to the standard drug[65].

3.8. Laxative

Ground flaxseed (6-24 g/day for three months) is more effective than psyllium (a bulk-forming laxative) in treating constipation. This may be due to the presence of insoluble fiber (33.2%) and soluble fiber (11%) along with 20% residue oil in ground flaxseed after cold-pressing[66]. The study confirmed the use of ground flaxseed as a laxative in irritable bowel syndrome.

3.9. Dry eye disease

Dry eye disease also called keratoconjunctivitis sicca is more common among elderly people and post-menopausal women. Using essential fatty acids in the treatment of dry eye disease

is gaining importance in recent years. Flaxseed oil (3.3 g ALA/day) was evaluated in patients with meibomian gland dysfunction and blepharitis (oil glands in eyelids get clogged or irritated and inflammation of the eyelids). The blood samples of the flaxseed oil-supplemented patients showed an increased level of omega-3 fatty acids and a decreased ratio of n6:n3. A significant improvement in the ocular surface disease index was also observed in flaxseed oil-treated patients compared with the olive oil placebo group[67]. These results confirm the possible utilization of flaxseed oil in the management of dry eye disease.

3.10. Kidney disorders

The ethanolic extract of flaxseed showed a beneficial effect on gentamycin-induced nephrotoxicity in rats and prevented acute kidney injury in an experimental animal model[68]. The protective effect of flaxseed oil against lead-induced kidney injury was also observed *in vivo*[69]. Oral administration of flaxseed oil for 12 weeks showed a higher bone mass in healthy rats and rats with kidney disease[70]. Flaxseed improved kidney functions in hypertensive rats[71]. Moreover, flaxseed and flax oil supplementation were effective in controlling renal function and reducing glomerular injury[72]. Lupus nephritis is a chronic kidney disease due to an autoimmune condition in the body. Consumption of flaxseeds can reduce the effect of lupus nephritis by reno-protective action[73].

3.11. Liver disorders

Daily supplementation of flaxseed cake or whole flaxseed powder 30 g/day for 12 weeks was found to be effective in the management of various parameters of non-alcoholic fatty liver disease such as body weight, liver enzymes, insulin resistance, hepatic fibrosis, and steatosis[74,75]. A randomized double-blind controlled trial involving 68 non-alcoholic fatty liver disease patients, showed the better efficacy of flaxseed oil over sunflower oil in improving the fatty liver and inflammation (IL-6 levels)[76]. Supplementation of flaxseed (30 g/day) improved central obesity and metabolic syndrome in a randomized controlled clinical trial involving 44 patients with metabolic syndrome[77]. In a pre-clinical model with CdCl₂-induced toxicity, flax oil significantly improved hepatic and renal histological lesions, decreased comet tail formation, and downregulated TNF- α and p53 levels in the liver[78].

3.12. Stomach ulcers

A study showed that pre-treatment with flaxseed oil and mucilage significantly reduced ethanol-induced gastric ulcers in rats by providing a cytoprotective effect[79]. This suggests that flaxseed can

be effectively utilized in the management of stomach ulcers which is a common problem in many alcoholic and non-alcoholic people.

3.13. Cystic fibrosis

Treatment of cystic fibrosis subjects with 40 g of flaxseed for 4 weeks resulted in a significant reduction in the urinary oxidative stress, which was mainly attributed to flaxseed metabolites *i.e.* enterolignans levels in plasma[80].

3.14. Infectious and non-infectious diarrhea

The effect of methanolic extract of flaxseed was evaluated in castor oil-induced diarrhea in mice. This extract showed bactericidal action and was effective against *Enterococcus faecalis*, *Escherichia coli*, *Staphylococcus aureus*, *Bacillus cereus*, *Pseudomonas aeruginosa*, and *Salmonella typhi*[81]. Oral supplementation of flaxseed oil and mucilage in mice showed antidiarrheal and laxative potential mainly through K(+) channel activation[82].

3.15. Other benefits

The human malarial parasite (*Plasmodium falciparum*) was controlled by an immunosuppressive peptide cyclolinopeptide A present in flaxseed[83]. Inhibitory activity of flaxseed proteins on bacteria especially against *Enterococcus faecalis*, *Salmonella typhimurium*, and *Escherichia coli* was observed under *in vitro* conditions[84]. Moreover, a reduction in menopausal-related difficulties and an improvement in bone health were observed when flaxseed was consumed by postmenopausal women[85,86].

4. Recommended consumption of flaxseed or ALA

Considering the crucial importance of flaxseed in the human diet, various international agencies have given recommendations regarding consumption of flaxseed/ ω -3 fatty acids. U.S. Department of Agriculture and U.S. Department of Health and Human Services in 2010 recommended a daily allowance of ω -3 fatty acids between 1.6 g/day for males and 1.1 g/day for females. International Society for the Study of Fatty Acids and Lipids in 1999 recommended 2.2 g ALA per day, while Eurodiet Commission in 2000 recommended 2 g ALA per day. French Apports Nutritionnels Conseilles in 2001 recommended 1.8 g ALA per day. Considering the daily requirement of ALA per day, approximately 7-9 g of flaxseed can be recommended for daily consumption[7,87].

5. Toxicity of flaxseed

One of the major hurdles in consuming flaxseed is the presence of anti-nutrients. Flaxseed contains two forms of cyanogenic glycosides *i.e.*, diglycosides (linustatin and neolinustatin) and monoglycosides (linamarin and lotaustralin). These cyanogenic compounds are known to produce hydrogen cyanide and may lead to cyanide poisoning hence consumption of raw/crude flaxseed is not recommended[88]. These components are eliminated or reduced when flaxseeds are subjected to thermal treatments like frying in a pan, cooking in microwaves, autoclaving, boiling, solvent extraction, and biological treatment to flaxseed/flaxseed cake[89,90]. Some studies showed that flaxseed anti-nutrients have lesser effects when compared to soybean and canola. Cadmium, linatine, phytic acid, and trypsin inhibitor are some of the other anti-nutrients present in flaxseed[91,92]. Daily consumption of three muffins (containing 32.7 g of total flaxseed) for 4 weeks did not show any toxic or deleterious effect on the hemopoietic system or renal and hepatic function. However, elevated serum triglyceride level was reported[93]. The consumption of flaxseed is not advisable in pregnancy, lactation, bleeding disorder, low blood pressure, bipolar disorder, food allergy, and gastric obstructions[94].

6. Conclusion

Extensive research is required to know further effects of flaxseed and its omega-3 fatty acids in the prevention of attention deficit hyperactivity disorder, eating disorders, preterm labor, emphysema, psoriasis, intraocular pressure, lupus, and male infertility[95–98] and they need further investigations and confirmation for specific recommendations. Flaxseeds are also used in Ayurvedic medicines like Virechana, which cleanses the sweat glands, colon, kidneys, stomach, liver, and spleens[99]. With the growing knowledge on the importance of flaxseed and its oil as a superfood, many industries/entrepreneurs are entering into processing, production, and sale of flaxseed/omega-3 fatty acid enriched eatables like soft gelatin flaxseed oil capsules, eggs, flaxseed oil emulsion, cold-pressed extracted virgin flaxseed oil, roasted and salted flaxseeds, multigrain pasta, oatmeal waffles, chocolate, flaxseed bread, flaxseed laddus, flaxseed milk, *etc.* Flaxseed and its oil need to be further popularized and properly utilized for the welfare of human well-being.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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Authors' contributions

CM contributed to designing the manuscript, data acquisition, data analysis and prepared draft of the manuscript. M. Sujatha and ALR conceptualized and reviewed the manuscript. M. Sandhanalakshmi contributed to detailed literature review of the manuscript. AAZ prepared final draft, and contributed to data acquisition and data analysis for manuscript preparation, manuscript editing and revision at every stage. All authors reviewed and approved the final version of the manuscript.

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