The Nutritional Science of Flaxseed: A Review of Functional Nutraceutical Benefits

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Abstract

Flaxseed (Linum usitatissimum), a traditional crop known for its nutritional richness and therapeutic applications, has garnered increasing interest as a functional food and nutraceutical. This review highlights the botanical characteristics, nutritional composition, and bioactive compounds of flaxseed, focusing particularly on alpha-linolenic acid (ALA), dietary Fiber, lignans, and high-quality protein. Clinical and experimental studies suggest that flaxseed consumption is associated with significant health benefits, including improved cardiovascular health, glycaemic control, renal function, cancer prevention, neuroprotection, and gut health. The review also emphasises the development of value-added food products incorporating flaxseed, reflecting its versatility in modern food systems. Despite its notable health potential, awareness about its therapeutic and functional roles remains limited. This review aims to consolidate existing scientific evidence and provide a detailed understanding of the role of flaxseed in nutrition, disease prevention, and functional food innovation.

Keywords: - Flaxseed (Linum usitatissimum), Functional food, Nutraceutical, Alpha-linolenic acid (ALA), Lignans, Cardiovascular health, Bioactive compound.

1. INTRODUCTION

The Lineaceae family includes flaxseed (Linum usitatissimum), a blue-flowering plant. It is called Alsi, Jawas, and Aksebija in Indian languages. The seeds are small and flat, and they can be golden yellow, reddish brown, or any other colour. Flaxseed has a crunchy and chewy texture and a nice nutty taste (Carter et al., 1996). In each of the five compartments of the round fruit capsules, there are two seeds. The seed is flat and round, with a pointy top. The surface is smooth and shiny. It can be as dark as brown or as light as yellow (Freeman 1995). People call flaxseed "flax" when they eat it, but they call it "linseed" when they use it for business (Morris et al., 2012). Almost every part of the linseed plant is useful in some way. The oil from the seed is processed and then used to make food (Singh et al., 2012). The stem makes high-quality fibre that is very strong and long-lasting. People have been eating flaxseed since before written history. People have grown it for its fibre, its health benefits, and its nutritional value (Tolkachev et al., 2000). Canada is the world's biggest producer of flax, making up about 38% of all flax production (Anonymous et al., 2000). The United States, Ethiopia, China, and India are the major producers of flaxseed (Singh 2011). Madhya Pradesh, Maharashtra, Chhattisgarh, and Bihar are the primary growing regions for flaxseed in India. It's fascinating to learn that flaxseed originated in India and was a staple crop. Flaxseed is still eaten as food and used medicinally in India (Shakir et al., 2007). Due to its many applications, it has a good standing among oilseeds. Because of its exceptionally high levels of dietary fibre, alpha-linolenic acid (ALA), high-quality protein, and phytoestrogens, it has become a popular nutritional food. About 35% fibre, 28% protein, and 55% ALA are found in flaxseeds (Carter et al., 1993). Genetics, growing conditions, seed processing, and analysis technique can all affect flaxseed's composition (Daun et al., 2003). Because of the potential health benefits linked to its biologically active components—dietary fibre, lignan, secoisolariciresinol diglyceride (SDG), and ALA—flaxseed has drawn increasing attention from nutritionists and medical researchers (Toure 2010). As a useful food, flaxseed is becoming more and more significant in the global food chain. According to Al-Okbi et al. (2005), a functional food is any food or food ingredient that may have physiological benefits and aid in the prevention or treatment of disease. Flaxseed currently has new opportunities as a functional food due to consumers' increasing desire for foods with exceptional health benefits. It has gained popularity as an ingredient in diets created especially for particular health benefits because of its superior nutritional profile and possible health advantages (Oomah et al., 2001). One of the necessary polyunsaturated fatty acids, ALA has been shown to have anti-inflammatory, anti-thrombotic, and anti-arrhythmic effects

(Dimopoulos et al.,1999). Nutritionists all over the world suggest the incorporation of omega-3 fatty acid sources in the diet. Flaxseed serves as the best omega-3 fatty acid source for the non-fish eaters. Edible flaxseed products include the whole flaxseed, ground meal, and extracted oil or mucilage. These products have been proposed as nutritional additives in the preparation of a number of dietary items such as baked cereal products, ready-to-eat cereals, fibre bars, salad toppings, meat extenders, bread, muffins, and spaghetti (Singh et al., 2012). In spite of the multiple clinical evidences of flaxseeds, people are still unaware about their nutritional as well as therapeutic benefits.

2. NUTRITIONAL COMPOSITION OF FLAXSEEDS

Because flaxseed contains a lot of lignans, soluble fibre, phenolic compounds, alpha-linolenic acid, and high-quality protein, it has potential as a functional food. shows the composition of specific seeds. The nutritional content of flaxseed is influenced by processing conditions, genetics, and the environment. Multiple studies have found that flaxseed's lipid content, especially in the cotyledons, varies between 37 and 45 lipids per 100 g of the seed. Alpha-linolenic acid is the primary functional ingredient in flaxseed. It's the only source of omega-3 fatty acids for vegetarians (Riediger et al., 2008). Two essential fatty acids, linolenic acid (LA) and alpha-linolenic acid (ALA), are abundant in flaxseeds. The high levels of α alpha-linolenic acid (ALA) in flaxseed oil may have cancer-prevention properties (Abou-El-Ela et al., 1988). According to (Tvrzicka et al.,2011), flaxseed oil is divided into three categories: monounsaturated, polyunsaturated, and saturated fractions. The total amount of unsaturated fatty acids is significantly higher than the limited amount of saturated fatty acids (Yaqoob et al., 2016). The main components of flaxseed oil extracted using petroleum ether were found to be stearic acid (C18:0, 10.7%), palmitic acid (C16:0, 12.9%), α-linolenic acid (C18:3, ω-3, 42.4%), and C18:2, ω-6, 26.2% (Ishag et al., 2019). Despite being a significant source of alpha-linolenic acid, scientists face significant challenges because flaxseed oil does not convert well to DHA (docosahexaenoic acid) and EPA (eicosapentaenoic acid) (Yang et al., 2021). According to a study, the lipid portion of flaxseed has a significant number of phospholipids, including phosphatidylethanolamine, phosphatidylinositol, phosphatidylcholine, lysophosphatidic choline, phosphatidylglycerol, and phosphatidic acid, along with a small amount of palmitic and stearic acids (Herchi et al.,2011). Flaxseed oil contains 4720–7550 mg of total sterols per kilogram (Dąbrowski et al., 2019). Flaxseed oil contains powerful antioxidants called toco chromanols. In comparison to Canadian and American cultivars, Pakistani and Egyptian cultivars had a higher total tocopherol content (Yaqoob et al., 2016).

Flaxseed has 21% protein (comprised of globulin and albumin), and the cotyledons contain most of the protein. The flaxseed proteins are more lipophilic than soya proteins (Madhusudhan & Singh, 1985). Arginine, aspartic acid, and glutamic acid are abundant in flaxseed protein, but lysine content is less (Chung et al., 2005). High quantities of methionine (0.322 g 100 g^{-1}) and cysteine (0.281 g 100 g^{-1}) increase antioxidant levels, which lowers the risk of cancer (Oomah, 2001). Flaxseed has a very low content of carbohydrates (28.9/100 g, out of which 27.3 g is dietary fibre and the remainder is sugar) (Food Data Central, 2018). Lignans are phytoestrogens that are widely distributed in plants that are high in fibre; the primary lignan in flaxseed is secoisolariciresinol diglycosidic, with low amounts of isolariciresinol, lariciresinol, pinoresinol, and metaraminol (Meagher et al., 1999). Secoisolariciresinol diglycosidic varies between 6.1 and 13.3 mg/g in whole flaxseed flour (Johnsson et al., 2000). Flaxseed lignin have antioxidant characteristics, which may be the main reason for the anticancer effect (Prasad, 1997). In obese postmenopausal women, dietary flaxseed slightly reduces the serum levels of steroid sexual hormones linked to the development of breast cancer (Sturgeon et al., 2008). Flaxseeds have both soluble (one-third) and insoluble (two-thirds) dietary fibre. Flaxseed stands out among the oilseeds because its outer layer has mucilage (Singhetal., 2011, 2012). Due to its functional properties, such as water-binding capacity, good foam stability, and exceptional health benefits, flaxseed mucilage has gained popularity (Mazza & Biliaderis, 1989). Soluble fibre is found in mucilaginous material made of water-soluble polysaccharides, while insoluble fibre is made up of cellulose, hemicellulose, and lignin (Oomah & Mazza, 1993). It has a potent ability to bind water, which is linked to the polysaccharides found in the seed coat (Fedeniuk & Biliaderis, 1994). The polysaccharides present in flaxseeds exhibit high rheological properties and a water-binding capacity comparable to guar gum (Kajla et al., 2015). Flaxseed mucilage is composed of both neutral and acidic polysaccharides (Wana Sundara & Shahidi, 1997). When flaxseed is consumed as a source of fibre, the colonic microflora in the large intestine produces short-chain fatty acids (SCFA), hydrogen, carbon dioxide, methane, and biomass, all of which have a laxative effect. Minerals, including calcium, magnesium, phosphorus, and salt, can be found in flaxseeds (Kajla et al., 2015). Flaxseed contains a small amount of water-soluble and fat-soluble vitamins. Flaxseeds contain tocopherol, which reduces the risk of heart disease, high blood pressure, and Alzheimer's disease, increases the excretion of salt in the urine, and shields proteins and lipids from oxidation (Kajla et al., 2015). Due to their high phenolic chemical content, flaxseeds can help prevent oxidative damage and cancer. In defatted linseed, the main phenolic acids found are chlorogenic, gallic, and ferulic acids; hydroxycinnamic acid glucosides, p-coumaric acid

glucosides, and 4-hydroxybenzoic acid are found in amounts (Beejmohun et al., 2007). Antinutrients present in flaxseeds may have a harmful influence on health. The principal antinutrients are cyanogenic glycosides, which are split into linustatin, neolinustatin, and linamarin (Oomah et al., 1992). Whole flaxseed contains a cyanogenic glycoside concentration of 250–550 mg/100 g (Singh et al., 2011, 2012). Phytic acid is also present in flaxseed (Oomah et al., 1996). It contains chelating qualities that diminish the bioavailability of proteins and minerals (Erdman, 1979). Flaxseed antinutrients have a smaller influence on human health than canola and soybean (Ganorkar & Jain, 2013), as flaxseeds contain a smaller number of trypsin inhibitors (Bhatty, 1993). animals, flaxseed consumption decreases cholesterol, whereas in others there is no effect (Parikh et al., 2019). Flaxseed decreases the quantity of trans fats in the blood (Bassett et al., 2011). Ventricular fibrillation is avoided in rabbits with a flaxseed-supplemented diet (Ander et al., 2004). The ALA content of flaxseed may be reducing the risk of myocardial infarction in the rat (Parikh et al., 2019). The conversion of SDG into enterolignans in the blood, however, might potentially have a cardioprotective impact (Prasad, 2009). Eating flaxseed maintains blood pressure. Patients with peripheral artery disease have ingested 30 g of milled flaxseed for 6 months on a daily basis and have shown a notable drop in their blood pressure (Rodriguez-Leyva et al., 2013). In animal experiments, acute or chronic administration of flaxseed protein hydrolysates or flax oil decreased blood pressure in spontaneously hypertensive rats (Ogawa et al., 2009).

TABLE-1: Nutritional composition of flaxseeds (Linum usitatissimum) (per 100 gm).

Name	Amount	Name	Amount	Name	Amount
Water	5.32–8.89g	Pantothenic acid	0.57–1.4mg	Fatty acids, total polyunsaturated	28.7g
Energy	534kcal	VitaminB-6	0.3–0.61mg	PUFA18:2	5.17–6.67g
Energy	2230KJ	Folate, total	35–112µg	PUFA18:3	18.7–26.2g
Protein	17–21.3g	Folate, DFE	87µg	PUFA20:2n-6c, c	0–0.015g
Total lipid(fat)	36.8–45.8g	Choline, total	78.7mg	Stigmasterol	9–14mg
Ash	3.42to4.07g	Betaine	3.1mg	Campe sterol	40–50mg
Carbohydrates, By the difference	28.9g	Lutein+ zeaxanthin	500–970µg	Beta-sitosterol	84–96mg

Fiber, total dietary	25.3–28.6g	Vitamin E (alpha-tocopherol)	0.23–0.45mg	Tryptophan	0.297g
Sugars, total including NLEA	1.55g	Tocopherol, gamma	14.3–25.8mg	Threonine	0.766g
Sucrose	0.84–1.51g	Tocopherol, delta	0.21–0.55mg	Isoleucine	0.896g
Glucose	0.21–0.73g	Vitamin K (phylloquinone)	3.7–4.8µg	Leucine	1.24g
Calcium, Ca	200–340mg	Fatty acids, total saturated	3.66g	Lysine	0.862g
Iron, Fe	3.67–7.32mg	SFA14:0	0–0.016g	Methionine	0.37g
Magnesium, Mg	354–431mg	SFA15:0	0.005g	Cystine	0.34g
Phosphorus, P	603–722mg	SFA16:0	1.67–2.58g	Phenylalanine	0.957g
Potassium, K	673–1000mg	SFA17:0	0.018g	Tyrosine	0.493g
Sodium, Na	21–45mg	SFA18:0	1.12–1.71g	Valine	1.07g
Zinc, Zn	3.95–4.92mg	SFA20:0	0.043–0.057g	Arginine	1.92g
Copper, Cu	1.07–1.52mg	SFA22:0	0.04–0.064g	Histidine	0.472g
Manganese, Mn	1.64–3.08mg	SFA24:0	0.031–0.032g	Alanine	0.925g
Selenium, Se	4.8–46µg	Fatty acids, total monounsaturated	7.53g	Aspartic acid	2.05g
Niacin	2.7–3.21mg	MUFA16:1	0.018–0.031g	Glutamic acid	4.04g
VitaminC, total ascorbic acid	0.5–0.7mg	MUFA18:1	6.86to7.91g	Glycine	1.25g
Thiamine	0.533–3.2mg	MUFA20:1	0.051–0.083g	Proline	0.806g
Riboflavin	0.161mg	MUFA22:1	0–0.027g	Serine	0.97g
Niacin	0.07–0.232mg	MUFA24:1c	Hydroxyproline	0.13–0.22g	0.13–0.22g

Food Data Central (2018). & Retrieved September (2022).

3. HEALTH BENEFITS OF FLAXSEEDS

Apart from its nutritional value, flaxseed exhibits health benefits due to its high levels of lignin, dietary fibre, and omega-3 linolenic acid. According to (Gogus and Smith 2010), fatty acids (ALA, DHA, and EPA) may provide therapeutic benefits against a variety of illnesses, including neurological conditions, atherosclerosis, cardiovascular disease, cancer, osteoporosis, immunology, arthritis, diabetes, and hypertension. Polyunsaturated fatty acids have been shown in several clinical investigations to have a strong anti-inflammatory impact

and to be useful in preventing coronary heart disease, atherosclerosis, rheumatoid arthritis, and asthma (Arend & Dayer, 1995). Flaxseed has been shown to have antiatherogenic, antiproliferative, and antiarrhythmic properties in addition to improving vascular function (Dupasquier et al., 2007). EPA and DHA are essential for reducing the symptoms of depression, according to several clinical studies (Kajla et al., 2015). demonstrates the many health benefits of flaxseeds.

3.1 EFFECT OF FLAXSEED CONSUMPTION ON CARDIOVASCULAR HEALTH

Nutritional management is thought to be a good way to avoid other issues. For instance, cutting back on saturated fatty acid (SFA) intake may lower the risk of CVDs since it helps regulate our body's total cholesterol levels. According to research, CVDs can be decreased by replacing polyunsaturated fatty acids with saturated fatty acids (Kleber et al., 2018). It is well established from several epidemiological studies and investigations that dietary components such soy protein, grains, plant sterols, and isoflavones may help to enhance the blood lipid profile. Utilising seeds and herbs are acknowledged as an additional successful therapy method to reduce the risk of CVD. Research on dietary flaxseed is both successful and growing, and there is a wealth of literature supporting its use and therapeutic benefits for a variety of illnesses (Parikh et al., 2019). The way flaxseed and its constituents may reduce the risk of CVD is seen in Figure 3. Flaxseed and its components reduce a number of markers and factors that increase the risk of CVD (Parikh et al., 2019). About 40% of patients with renal diseases are hyper-lipidemic, despite the fact that 69% of people with metabolic syndrome are hypercholesterolemic and 65% of people with metabolic syndrome are hyper triglyceridemic (Pilar et al., 2017). This indicates that the prevalence of high blood lipid is rising quickly. The development and progression of atherosclerotic plaques are mostly brought on by hyperlipidaemia, which ultimately results in coronary heart disease. As a 10% reduction in total serum cholesterol levels lowers the risk of cardiovascular disease by 30%, nutritional interventions have a significant role in preventing heart disease by lowering blood lipids (Hadi et al., 2020). Numerous studies have demonstrated that CVD may be prevented by adopting healthy lifestyle choices, including dietary changes, quitting smoking, and increasing physical activity (Pilar et al., 2017). This article aims to assess flaxseed's effects on a variety of conditions, including diabetes, liver disorders, and hyperlipidaemia.

3.2 EFFECT OF FLAXSEED CONSUMPTION ON DIABETES

Dietary interventions, as opposed to pharmaceutical therapy, can prevent diabetes. Recent studies have shown that including flaxseed in the diet may help diabetics by lowering insulin resistance and also acts as a preventative measure to lower the risk of developing diabetes. Flaxseeds are thought to prevent diabetes by maintaining insulin sensitivity in phospholipid membranes because of their essentially high content of omega-3 and omega-6 fatty acids (Bhardwaj et al., 2015). Flaxseed consumption has been shown to have a positive impact on people with diabetes and pre-diabetics based on a number of epidemiological studies, clinical trials, and experiments. Other components of flaxseed include 32% to 45% of its mass as oil, 51% to 55% of which is made up of alpha-linolenic acid, and 15% to 18% of which is linoleic acid. SDG is a lignin that is widely found in flaxseed. SDG contains between 0.6 and 1.8 g of flaxseed per 100 g. In addition to being antioxidants, cinnamic acid and SDG metabolites have a hypoglycaemic effect. Because of the low expression of the phosphoenolpyruvate carboxin (PEPCK) gene, SDG has a hypoglycaemic effect. According to Prasad and Dhar (2016), PEPCK is an enzyme that slows down the liver's rate of gluconeogenesis. the likely processes by which flaxseed prevents diabetes. studied 25 postmenopausal women and men who were overweight or obese and had pre-existing diabetes. Over the course of 12 weeks, the participants were given 0, 13, or 26 g of ground flaxseed to consume. The results showed that compared to the other two groups, the group that consumed 13 g of flaxseed daily had significantly lower blood glucose levels (Hashemzadeh et al., 2017). According to a different study, moderate consumption of flaxseed helped lower blood glucose levels, but neither a high nor a low dose of flaxseed affected glycaemic control (Mohammadi-Sartang et al., 2018).

3.3 EFFECT OF FLAXSEEDS CONSUMPTION ON RENAL HEALTH

Chronic kidney disease is one of the biggest health issues affecting older adults. It can lead to end-stage renal disease and require dialysis or a kidney transplant to survive (Coresh et al., 2007). Some hypothesised that ω-3 fatty acids, with their anti-inflammatory properties, could shield the kidneys from harm. An outstanding source of ω-3 fatty acids is flaxseeds. Supplementation with polyunsaturated fatty acids has been shown to reduce inflammation and renal fibrosis (Baggio et al., 2005). There was an inverse relationship between the dietary intake of polyunsaturated fatty acids and the incidence of chronic kidney disease (Gopinath et al., 2011). Chronic consumption of omega-3 fatty acids was linked to a significant decrease in both diastolic and systolic blood pressure. The way polyunsaturated fatty acids affect blood pressure may be a practical way to avoid kidney damage (Cicero et al., 2010). The lignan and gum derived from flaxseed also reduced blood glucose levels in individuals with type 2 diabetes

(Pan et al., 2007). Rats with type I diabetes have shown antihyperglycemic effects from flaxseed lignan in preclinical studies (Prasad et al., 2000). Hutchins et al. (2013) found that consuming 13 g of flaxseeds daily decreased fasting plasma glucose levels. In another experiment, a 20 g daily flaxseed diet for three months significantly reduced insulin resistance and increased insulin sensitivity (Javidi et al., 2016). Heart disease patients who took flaxseed oil as a supplement for three months showed improvements in PPAR-γ, LP(a), IL-1, and TNF-α gene expression (Hashemzadeh et al., 2017). Another study found that giving female rats SDG orally prior to the onset of diabetes reduced their risk of developing the disease by 80% (Corsetti et al., 2000). After eating chapatti, which is made up of 5 g of flaxseed and 25 g of wheat flour, for three months, 20 diabetic patients were compared to the control group in order to assess the antidiabetic effect of flaxseeds on type 2 diabetes. The findings showed a decrease in plasma glucose levels (Pradhan et al., 2017).

3.4 EFFECT OF FLAXSEED CONSUMPTION ON CANCER

Numerous tumours have already been effectively treated with flaxseed in animal experiments (Mason & Thompson, 2014). Dietary flaxseed has been demonstrated to dramatically lower the incidence of breast cancer in animal studies and in human trials (Calado et al., 2018). Flaxseed slows down the development of tumours in breast cancer patients (Flower et al., 2013). Intestinal bacteria break down flaxseed lignins to make them accessible in plasma (Gaya et al., 2016). Before being absorbed through the intestinal wall, lignins received from food are primarily found as glucosides and transformed into enterodioland enterolactone inside the gut through several methods. The large intestine absorbs these chemicals (Kuijsten et al., 2005). In postmenopausal breast cancer patients, greater blood enterolactone concentrations have been connected with a reduced risk of breast cancer. Lignin lowers the death rate from breast cancer by 33%–70%, while the total mortality rate falls by 40%–53%. ALA possesses anti-inflammatory effects (Mali et al., 2019). Flaxseed oil increases the anticancer effects of medications used in oncotic therapy (Mason et al., 2010). When flaxseed was administered with tamoxifen, it improved the anticancer effects (Calado et al., 2018). The regulation of estragon metabolism, suppression of inflammation, metastasis, angiogenesis, and cellular proliferation, as well as activation of apoptosis inside the tumour, are a few of the cellular oncotic pathways that flaxseed and its bioactive components. Flaxseed and its bioactive components have anticancer actions via decreasing the phosphorylation of p-AKT, p-ERK, and p-JNK kinases, inhibiting CDK4 (Shah & Patel, 2016).

3.5 EFFECT OF FLAXSEED CONSUMPTION ON THE BRAIN

Omega-3 fatty acids are essential for brain development. Although DHA is also essential for the development of the brain before and after pregnancy, EPA tends to influence behaviour and mood (Lauritzen et al., 2016). Reduced learning and spatial performance have been linked to DHA depletion (Salem et al., 2001). These results indicate that the ω-3 fatty acids, which are abundant in flaxseed, may have a similar beneficial effect on the brain. Rat mothers who consumed flaxseed during pregnancy produced pups with brains that were significantly richer in ALA and DHA and heavier overall. Puppies who were fed flaxseed oils or milled flaxseed shortly after birth had larger brain masses, indicating the value of milled flaxseed for promoting early postnatal brain development (Pessanha et al., 2015). Nonetheless, consuming flaxseeds continuously to increase brain growth and spatial memory over an extended period of time results in an imbalance between ω-3 and ω-6 fatty acid levels (Fernandes et al., 2011). When rats were exposed to moderate stress for a long time, flaxseed reduced all aspects of chronic stress (Naveen et al., 2013). In rats exposed to chronic stress, flaxseed lignin has been shown to exhibit antidepressant effects (Ma et al., 2012) and to shield cortical neurones from NMDA-induced neurotoxicity (Li et al., 2012).

3.6 OTHER HEALTH BENEFITS

In a 12-week study, flaxseed oil consumption improved a number of skin characteristics in healthy female volunteers with sensitive skin. While skin hydration and smoothness were improved, skin sensitivity, trans epidermal water loss, roughness, and scaling were reduced. Supplementing with flaxseed has been shown to balance pro- and anti-inflammatory oxylipins, which may have a positive impact on ageing (Caligiuri et al., 2014). The quantity and variety of Enterobacteriaceae in the mouse faeces were impacted by the inclusion of flaxseed in the mice's diet (Pulkrabek et al., 2017). A diet supplemented with flaxseed will increase intestinal Bifidobacterium (Patterson et al., 2014). Consuming flaxseed oil may help treat alcoholic liver disease by lowering the number of porphyromonadaceae and proteobacteria in the colon (Zhang et al., 2017). Flaxseed had no effect on the faecal microbiota, according to (Lagkouvardos et al., 2015). Flaxseed's bioactive peptides have strong antimalarial and immunosuppressive properties (Bell et al., 2000). In vitro antioxidant properties and the ability to inhibit the activity of the angiotensin I-converting enzyme (ACE) were demonstrated by

peptides produced by the enzymatic hydrolysis of flaxseed proteins (Marambe et al., 2008). In one study, people with type 2 diabetes who were experiencing constipation were given flaxseed cookies. The study found that flaxseed reduced fasting blood glucose, lipid levels, and constipation symptoms (Soltanian & Janghorbani, 2018). Flaxseed again improved all the variables and significantly outperformed psyllium in terms of its ability to reduce constipation symptoms in a second experiment involving the same group (Soltanian & Janghorbani, 2019). Diarrhoea symptoms can be reduced by using flaxseed oil (Hanif Palla & Gilani, 2015).

4. NUTRACEUTICAL OR FUNCTIONAL FOOD OF FLAXSEED

There is a difference between the terms "functional food" and "nutraceutical," despite the common misconception that they are interchangeable. A functional food is one that looks like a regular meal, is consumed as part of a regular diet, has physiological benefits that have been proven, and/or reduces the risk of chronic illness in addition to serving basic nutritional purposes. A nutraceutical, on the other hand, is a product that has been extracted or purified from food and is mainly sold in therapeutic forms; it is not often associated with food (Health Canada 1998). While functional foods often require additional nutrients beyond those required for normal maintenance, growth, and development, nutraceuticals can be a component of these foods. Flaxseed can be regarded as a functional food since it is consumed as whole, ground, or roasted seeds, oil, and flour to provide basic nutrition and a number of health benefits, including lowering LDL cholesterol, preventing cardiovascular disease and cancer, and promoting vasodilatory effects. However, the market offers a variety of stable flaxseed preparations in the form of nutraceuticals, including microencapsulated powder, capsules, and plain oil. Commercially available SDG formulations made from flaxseed lignans are also available as dietary supplements (Chen et al. 2011b). Additionally, flaxseeds were used as medicines in antiquity to treat coughs and stomachaches. The following category describes the various therapeutic flaxseed/oil formulations that are offered in international markets. Flax may therefore be regarded as a potential nutraceutical and functional food when all of these concepts are taken into consideration.

5. DEVELOPMENT OF VALUE-ADDED PRODUCTS OF FLAXSEEDS

Value-added products are developed to increase the value of items by adding ingredients, processing them, or using special packaging. Compared to original commodities, value-added foods are more appealing and acceptable to consumers (Kaur et al., 2018). represents some value-added products that can be developed with flaxseeds. One of the most organised sectors

of the processed food business is the baking industry. The ease of transportation, affordability, availability of a wide range of flavours, and textural features make bakery items appealing. The ability to be fortified with grains, millet, or other components is the bread goods' main advantage (Gat & Anantha Narayan, 2014).

Flaxseed Form	**Method of Processing/ Products Name**	**Flaxseed Supplementation**	**Mechanism**	**Reference**
Roasted flaxseed, flour	Biscuits	10,25 & 43%	10%flaxseed quality (Moisture content, fortification, dark colour, texture) and nutritional value without undesirable change. Flaxseed flour with 30% acceptable and 40%	Masoodi, 2012
Flaxseed flour	Bread	10,15,20 & 25%	Ground flaxseed10%: loaf volume, Dallman degree, nutritional content (linolenic acid and-tocopherol), and staling brad. Flaxseed flourusedwith15% sensory acceptability Coated and uncoated ground flaxseed, water absorption due to rich in oil can coat	Mente, 2008
Flaxseed oil	Ice-cream	0-12%	Meltdown rate, ice cream hardness linear to concentration.	Goh, 2006
Whole flaxseed flour	Muffin or snack bar	30g per muffin or bar	Flaxseed aroma, sweetness, vanilla aroma, bitter taste, while no intensities on gingerbread raisin snack, spice aroma, nutritional value.	Aliani, 2011
Flaxseed	Flaxseed boll	1g per each boll	Flaxseed balls under a cooking treatment balanced-3/-6 ratio, stable fatty acids profile, gynogenic glycoside, 16days after Anthes is bolls were more stable compared to 8days after Anthes is underheat treatment with good taste, texture, and aroma.	Fofana, 2011
Flaxseed flour	Corn snack	Up to 20%	Puffy extruded, probably due to protein and fat competition for water with starch	Ahmed, 1999
Roasted flaxseed flour	Pan bread & Pizza	10,15 & 20%	Flaxseed with 15% protein, fat, Fiber, carbohydrates, and total serum cholesterol.	Ahmed, 2010
Flaxseed cake flour	Pita bread	5,10,15 & 20%	15&20% flaxseed Water absorption due to protein and mucilage, mixing time (4.43min) of dough, extension(elasticity)of dough, water holding capacity,	Khattab, 2012

			moisture content, flaxseed cake flour, alkaline water retention capacity.	

Roasted, ground, milled, whole, or in the form of oil, flaxseed may all be used in baking. Due to the flaxseed's oxidative instability at high temperatures and during storage, adding flaxseed to bread items has proven to be difficult for many research projects. According to recent research, flaxseed has been used in a variety of bakery goods in varying amounts, including bagels, bread, muffins, cookies, pizzas, patties, biscuits, and buns (Kaur et al., 2019). The incorporation of flaxseeds into baked goods and cereal items had a significant impact on improving overall nutritional quality. Functional bread made from a combination of flaxseed and refined flour had better water absorption, stickier dough, and a softer crumb texture (Marpalle et al., 2014). Compared to control muffins, flaxseed muffins (7.3%, 11.6%, and 15.5%) scored worse on sensory measures, yet they nevertheless met 16% of the daily need for fibre (Ramcharitar et al., 2005). The incorporation of flaxseed into wheat flour showed that the products' mineral, fat, protein, and dietary fibre contents improved while their carbohydrate content decreased (Kaur et al., 2018). Hypoallergenic formulations for babies with milk hypersensitivity that include hydrolysed protein, milk enhanced with calcium and vitamins, and so forth are examples of value-added dairy products that can be prepared by incorporating flaxseeds (Özer & Kirmaci, 2010). Dairy products, including butter, whey, cheese, yoghurt, and ice cream, have also been supplemented with flaxseed oil and lignan. Without substantially impacting the overall functioning of the ice cream, 2% (w/w) flaxseed oil may be added to a 12% (w/w) ice cream mixture. It was discovered that SDG applied to milk, yoghurt, and cheese can effectively tolerate fermentation, renneting, and pasteurisation (Hyvärinen et al., 2006). Dahi (Indian yoghurt) was enriched with microencapsulated flaxseed oil powder in three distinct formulations: 1%, 2%, and 3%. This might be used as a possible delivery route for ω-3 fatty acids (Goyal et al., 2016). In the continuous shearing, mixing, cooking, and shaping process, extrusion cooking technology is important in many food-processing sectors (Ananthanarayan et al., 2018). Ready-to-eat meals, snacks, confectionary items, and crisp bread are just a few of the meals and feed products that may be produced using it. Extruded meals are mostly accepted by consumers because of their convenience, affordability, appealing look, and unique texture (Anton et al., 2009).

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