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Review Article

Flaxseed and Seed Oil: Functional Food and Dietary Support for Health

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Abstract: *Linum usitatissimum* commercially known as Flax or flaxseed is mainly considered as an oilseed crop all over the globe belonging to the family Linaceae. Flax was valued in Ancient and Early Modern times as both food and medicine. Linseed has an important position in the Indian economy due to its wide industrial utility. In recent years, it emerged as a main key resource of phytochemicals in nutritional and functional aspects of human health. Moreover, due to other nutritional considerations than its oil content, make it a more favorable choice for food technologists and nutritionists to develop it as a functional food. Several studies divulge that these ingredients work well for nutritional advantage for human beings. Scientific evidence suggests and supports flaxseed consumption due to its quality proteins, soluble fibers, and a rich source of phenolic compounds. However, a large sector of the population all over the globe is still unaware of the health benefits supplementary to its consumption and its possible applications as useful food ingredients in food and food products. Flaxseed is mainly known for its high alpha-linolenic acid content, but it is also a rich source of lignan, compounds which are biologically active in the prevention of some chronic diseases. Flaxseed dietary fiber exhibits positive effects to reduce constipation, keep better bowel movement, and as a hypocholesterolemic agent. Over and above, numerous researchers reported that flaxseed incorporated food products can have good customer adequacy along with their nutritional welfares.

Keyword: Flax, flax seeds, functional food, health benefits, nutrition.

INTRODUCTION

Linseed or flax (*Linum usitatissimum* L.) belongs to the order Malpighiales, the family Linaceae, and the tribe Lineae. It is the second most important *rabi* oilseed crop and stands next to rapeseed-mustard in the area of cultivation and seed production in India. The genus *Linum* is composed of approximately 230 species but cultivated linseed/flax is the only species of economic importance in the genus (Tadesse *et al*., 2010) and is one of the oldest plants cultivated for fiber and oil. Linseed is popularly known as Linsed in Telugu and Kannada, *Alsi* in Hindi and Gujarati, *Jawas* in Marathi, *Alivitai* in Tamil, or *Tisi* in Odia. Although linseed plants have several utilities, it is cultivated commercially for their seed, which is processed into oil, and after extraction of oil, a high protein stock feed is left (Kurt and Bozkurt, 2006). Humans have been eating flax in various forms for thousands of years. Since ancient times flax seeds are considered to be the most efferent health booster. Nutrition plays an important part in human life. It is generally accepted that linseed has originated from ―Fertile Crescent‖ - an area east of the Mediterranean Sea towards India (Zeven and Zhukovsky, 1975; Anonymous, 2010) and was probably first domesticated there. Linseed is commonly known as Flax or flax seed and scientifically known as *Linum usitatissimum* L. The generic name came from *Lin* means fiber or thread, the species name *usitatissimum* means most useful. Plant products have gained well-deserved attention from all over the globe. Flax Council of Canada gave the chronology of Linum seed wherein the first report was given by Hippocrates, the father of medicine, and Theophrastus in 650 B.C. who advocated flax for the relief of abdominal pains and recommended the use of flax mucilage as a cough remedy. About 15th century A.D. Hildegard von Bingen used flax meal in hot compresses for the treatment of both external and internal ailments. Moghaddasi (2011) gave the various uses of flax consumption properly. Ayurveda as well as TCM remains one of the most ancient and yet alive traditions practiced widely in SARC countries that have a sound philosophical and experimental basis

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(Patwardhan *et al*. 2004). Atharvaveda (around 1200 BC), Charak Samhita (Dash and Sharama 2001), and Sushrut Samhita (1000–500 BC) are classic treaties that give detailed descriptions of numerous herbs. Even today contemporary idiom, best attempted with a commentary from modern medicine and science viewpoint, gives some glimpses of ancient wisdom (Valiathan 2003).

Linum usitatissimum cultivated commercially as a field crop is generally considered as a non-edible oilseed in developed nations (USDA, 1991). The flax plant has a small much-branched stem with narrow leaves and beautiful blue flowers. Flax seeds are flat and oval with a pointed tip and their color varies from dark brown to yellow. Linseed was valued in ancient as well as present times as both food and medicine. The small difference in using the terms flaxseed and linseed; Flaxseed is used to describe flax when consumed as food by humans while, linseed is used to describe flax when it is used in the industry and feed purpose (Morris, 2008). Linseed has been a neglected crop in India, because of low productivity and low market demand. In the last two decades, flaxseed has been the focus of increased interest in the field of diet and disease research due to the potential health benefits associated with some of its biologically active components (Goyal *et al*. 2013). Consumption of flaxseed and seed oil in various forms and various preparation dates from 5000 BC since its cultivation. In India, it is cultivated and used by the rural population for ages. Flaxseeds have been classified as a functional food because it provides many health benefits as it is the main source of omega-3 fatty acid, alpha-linolenic acid, and a phenolic compound known as lignans. These and other phytoconstituents of flaxseed make it one of the six nutraceuticals and may be considered as the first cultivated superfood. In addition to serving as a rich source of nutrients, the functional attributes of many traditional foods are also being discovered. Flaxseed is grown either for the production of oil or fiber (Vaisey-Genser and Morris, 2003).

Scientific research after human diet and health has evolved in the last few years and the concept of functional foods started getting popular globally. The functional foods that have prospective benefits for the common man's health have grown enormously. Foods that are advertised as being functional 'are thought to exert certain positive properties over and above their normal nutritional value. The medicinal power of foods has been a widely accepted philosophy for generations all over the globe. Hippocrates has stated the functional food movement almost 2,500 years ago 'Let food be thy medicine and medicine be thy food. In today's world, consumers' beliefs in the health benefits of selected foods seem to be increasing at an unparalleled pace due to their necessity and their components in numerous lifestyle disorders. The medicinal applications of linseed are mentioned in the works of Hippocrates, Qantes and Dioscorides as well as in medieval books on medicinal herbs in both Asia and Europe. Various edible forms of flax are available in the food market—whole flaxseeds, milled flax, roasted flax, and flax oil. These functional foods are associated with various types of benefits such as vitamin source and mineral fortification, cholesterol reduction, antioxidants, phytochemicals, dietary fiber, herbs and botanicals, probiotics, prebiotics and synbiotics, organic and inorganic micronutrients, vitamins, some proteins (e.g. lactoferrin), certain bioactive peptides and polyunsaturated fatty acids (Gibson, 2007). It is very rich in essential omega-3 fatty acid and modern food is very deficient in Omega-3 fatty acid. Hence, today the increase in severity and incidences of several degenerative diseases including cardiovascular disorders, diabetes, cancer, arthritis, mental illness, etc. has been attributed to this deficiency. Flaxseed continues to surge forward in its recognition as a functional food. Flaxseed has been in the focus of nutritionists and medical researchers due to its latent health aids associated with its biologically active components and to its physicochemical composition-ALA, lignan- Secoisolariciresinol diglycoside (SDG) oil, protein, dietary fiber (Toure and Xueming, 2010), soluble polysaccharides, phenolic compounds, vitamins (A, C, F, and E) and minerals (P, Mg, K, Na, Fe, Cu, Mn, and Zn) (Bhatty 1995; Jheimbach and Port Royal 2009). Linseed is also a very rich source of lignan particularly SDG (Secoisolaricinol Diglucoside) is a phytoestrogen, with several pharmacological properties including cardio-protective and anti-breast cancer properties, already produced by many companies in the US and China and sold as of the counter product. Despite the multiple clinical as well as scientific pieces of evidence of linseed, people are still ignorant about its actual components, nutritional, therapeutic, and other health profits.

Nutritional composition of flaxseed

Till the 20th century, the health-related benefits of flaxseed, as well as consumption of flaxseed to attain any health benefits, were little known globally. Research information on the effects of dietary flaxseed has increased dramatically and has impressive research works supporting its use in a variety of health conditions. The demand for flax in food and beverages, functional foods, and dietary supplements has risen dramatically due to the presence of α-linolenic acid for vegetarian people and is considered to be a complete functional food. Moreover, positive effects on disease prevention providing health-beneficial components are also reported (Bozan and Temelli, 2008). Flaxseeds have nutritional characteristics and are a rich source of ω-3 fatty acid: α-linolenic acid (ALA), short-chain polyunsaturated fatty acids (PUFA), soluble and insoluble fibers, phytoestrogenic lignans (secoisolariciresinol diglycoside-SDG), proteins, and an array of antioxidants (Ivanova *et al*. 2011; Singh *et al*. 2011; Alhassane and Xu 2010). The major nutritional

components of flaxseed include oil, lignin-rich fibers, protein, and minerals. Flaxseed has become known as a functional food due to its nutritional composition. The total protein content ranges between 20 to 30% in flax seeds and is composed of mainly 80% globulins and 20% glutelin. Flaxseed is a source of good-quality protein and albumins and globulins are the storage proteins of flaxseed with globulins forming the highest portion (Hall *et al*., 2006). Cellulose, hemicellulose, and lignin are insoluble fiber constituents abundantly found in flaxseed while mucilage gums form the soluble fiber fraction (Morris, 2007). Flaxseed is an equally good source of minerals, particularly, phosphorus, magnesium, calcium, iron, zinc, and very little amount of sodium. Flaxseeds also contain anti-nutrients that may pose adverse health effects and may influence the well-being of the human population. Flaxseed is high in most of the vitamins, magnesium, and manganese, and is low in saturated fatty acids. The major lignan present in flaxseed is secoisolariciresinol diglycoside (SDG). Major antinutrients in whole flaxseed are cyanogenic glycosides (250– 550 mg/100 g) (Singh *et al*., 2011). The nutrient profile of Flax seeds is given in table 1.

Owing to the presence of the above-mentioned phytoconstituents in modern food science it is placed in functional food. Alpha-linolenic acid is the main functional component of flaxseed. It serves as an exclusive source of omega-3 fatty acid (Riediger *et al.*, 2009) and are termed essential because the body cannot synthesize them (de Lorgeril *et al*., 2001). There are two groups of omega fats: omega-3 and omega-6 fatty acids. Linolenic acid, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) are three types of omega-3 fatty acids and are nutritionally important, for that reason it needs to be supplied in the diet. Flaxseed protein content varies from 20 to 30 % and has 80%globulins (linin and conlinin) and 20 % glutelin (Hall *et al*. 2006). Whole flaxseed, flaxseed meals, and isolated proteins are rich sources of glutamic acid/glutamine, arginine (Oomah and Mazza 1993), branched-chain amino acids (valine and leucine), and aromatic amino acid (tyrosine and phenylalanine). Although, due to the presence of amino acid- lysine hence it is not considered to be a complete protein (Chung *et al*. 2005).

Flax fiber

Flax fiber is extracted from the skin of the stem of the plant. It is the oldest fiber crop in the world and linen production goes back at least to ancient Egyptian times. Fibers obtained from the stem are known for their length and strength and are two to three times as strong as those of cotton (Taylor, 2012). The fiber is lustrous and blends very well with wool, silk, and cotton, etc. Flax fiber is soft, lustrous, and flexible and is stronger than cotton fiber but less elastic (Singh *et al*. 2011). Flax fibers include both soluble and insoluble dietary fibers. The major insoluble fiber fraction contains cellulose and lignin, and the soluble fiber portions are the mucilage gums (Vaisey-Genser, 2003). Insoluble fiber helps in laxation and prevents constipation, mainly by increasing fecal bulk and reducing bowel transit time (Greenwald *et al*. 2001). According (Kristensen *et al*. 2012) water-soluble fiber helps in sustaining blood glucose levels and lowering blood cholesterol levels.

Flax lignan

In addition, Flax contains up to 800 times more lignans than other plant foods (Mazur *et al*. 1996; Westcott and Muir 1996). Lignans act as both antioxidants and phytoestrogens. Phytoestrogens can have weak estrogen activity in animals and humans. Lignan content in flaxseed is principally composed of secoisolariciresinol diglucoside (SDG) (294–700 mg/100 g), matairesinol (0.55 mg/100 g), lariciresinol (3.04 mg/100 g) and pinoresinol (3.32mg/100 g) (Tourre and Xueming 2010; Milder *et al*. 2005).Besides lignans, other phenolic compounds found in flaxseed are p-coumaric acid and ferulic acid (Strandas *et al*. 2008). Over and above, Flax lignans have shown promising effects in reducing the growth of cancerous tumors, especially hormone-sensitive ones such as those of the breast, endometrium, and prostate (Tham *et al*. 1998). Flaxseed is the richest source of plant lignans (Thompson *et al*., 1991). Lignans are phytoestrogens, which are abundantly available in fiber-rich plants, especially in linseed; total dietary fibers are 27.3 per g which makes it a major source as it contains about 75-800 times more lignans than cereal grains, legumes, fruits, and vegetables (Hosseinian and Beta 2009). Secoisolariciresinol diglycoside (SDG) is the major lignan of flaxseed, along with minor contents of matairesinol, pinoresinol, lariciresinol, and isolariciresinol (Sicilia *et al*., 2003; Krajcova *et al.*, 2009). The behavior of the lignans depends upon the biological level of estradiol. Linseed has 1-3% lignan and is also one of the very rich sources of lignan. This gets readily converted into mammalian lignan with estrogenic activity in the human body. This molecule is of tremendous pharmacological importance. It has been shown to be very useful for treating and preventing postmenopausal syndrome in women, arthritis, osteoporosis, and breast cancer. It has also been shown to have anti-atherogenic activity.

Flaxseed oil

Flaxseed oil is believed to bring mental and physical endurance by fighting fatigue and controlling the aging process. According to Ayurveda, flaxseed has properties like Madhura(balances the skin pH), Picchaila (lubricous) Balya (improves tensile strength or elasticity of the skin), Grahi (improves moisture holding capacity of skin), Tvagdoshahrit (removes skin blemishes), Vranahrit (wound healing) and useful in Vata (skin) disorders including dryness, undernourishment, lack of luster/glow (Misra 1963). Linseed oil continues to be the base stock in medicinal, chemical, pharmaceutical and cosmetic industries as

they have renewable, biodegradable properties and are non-allergic in nature along with enriched phytochemical contents. Linseed holds the key to omega-3 nutritional security. Flaxseed oil is a rich source of essential fatty acids (EFAs): linoleic acid (ω-6) and α-linolenic acid (ω-3), which regulate prostaglandins synthesis and hence induce wound healing process. Linseed holds the key to omega-3 nutritional security. Deficiency of EFAs results in phrynoderma or toad skin, horny eruptions on the limbs and poor wound healing, etc. Flax preparations were widely used in medicine as an enveloping and wound-healing agent in the treatment of gastrointestinal disorders (Ivanova *et al*. 2011). In the middle ages, flaxseed oil was administered as a diuretic for the treatment of kidney disorders (Moghaddasi 2011). Flaxseed was recommended as an antitumoral (in combination with sweet clover), pain and cough relieving, and anti-inflammatory remedy (Tolkachev and Zhuchenko 2000; Moghaddasi 2011). It was also used for the treatment of freckles (in a mixture with soda and figs) and nail disorders (with garden cress and honey) (Tolkachev and Zhuchenko 2000).

Although, flaxseed oil is naturally high in anti-oxidant like tocopherols and betacarotene, traditional flaxseed oil gets easily oxidized after being extracted and purified (Holstun and Zetocha 1994). Flaxseed is the richest plant source of theω-3 fatty acid i.e. α-linolenic acid (ALA) (Gebauer *et al*. 2006). Flaxseed oil is low in saturated fatty acids (9%), moderate in monosaturated fatty acids (18 %), and rich in polyunsaturated fatty acids (73 %) (Cunnane *et al*. 1993). Of all lipids in flaxseed oil, α- linolenic acid is the major fatty acid ranging from 39.00 to 60.42 % followed by oleic, linoleic, palmitic, and stearic acids, which provides an excellent ω-6:ω-3 fatty acid ratio of approximately 0.3:1 (Pellizzon *et al*. 2007). Boiled linseed oil is one of the widely used surface treatment materials for the protection of concrete structures (Pfeifer and Scali, 1981). It can be used either in the form of a solution or emulsion.

Health benefits

Flaxseed has potential health benefits besides nutrition, due to mainly 3 reasons: first, due to its high content ofω-3 α-linolenic acid; Second, being rich in dietary soluble and insoluble fibers; and third, due to its high content of lignans, acting as antioxidants and phytoestrogens. ALA can be metabolized in the body into docosahexaenoic acid (DHA) (ω-3) and eicosapentaenoic acid (EPA) (ω-3). The health benefits of all ω-3 fatty acids (ALA, EPA, and DHA) have been widely reported for several conditions including cardiovascular disease, hypertension, atherosclerosis, diabetes, cancer, arthritis, osteoporosis, autoimmune and neurological disorders (Simopoulos 2000; Gogus and Smith 2010). Flaxseed has also been reported to act as an anti-arrhythmic (Ander *et al*. 2004), anti-atherogenic, and anti-inflammatory (Dupasquier *et al*. 2007) agent in addition to improving vascular function (Dupasquier *et al*. 2006). In table 2 recent researches on flaxseed as a portion of food and nutraceuticals is presented.

Traditionally, obesity-related disease conditions have been often treated and/or prevented using many plant materials including flax (Singh *et al*. 2011; Santos *et al*. 2010). Flaxseed fibers form highly viscous solutions upon hydration, which is similar to those observed for other gums (Goh *et al*. 2006). Particularly viscous fibers appear effective in suppression of hunger (Wanders *et al*. 2011; Kristensen *et al*. 2011).

In Western societies, constipation remains a major health problem mostly due to refined diet. It is well known that a sufficient amount of dietary fiber is a cornerstone in the prevention and treatment of constipation (Tarpila *et al*. 2005). The metabolism of flaxseed fiber can be stated as with any dietary fiber. Dietary fiber as a natural way to manage irritable bowel syndrome made it the first-line treatment for this condition during the 1970s and 1980s.

Concerning the protein fraction, flax is not actually used as a source of food protein but used in animal feed as a cheaper material (Rabetafika *et al*. 2011). This also enhances the fat proportion in the milk of the cattle. Recent reports have shown various techno-functional properties (Wang *et al*. 2010a; Mueller *et al*. 2010a, b; Green *et al*. 2005) and health benefits of flaxseed proteins. peptides derived from enzymatic hydrolysis of flaxseed proteins inhibited angiotensin I–converting enzyme (ACE) activities, and also displayed in-vitro antioxidant activities (Omoni and Aluko 2006; Marambe *et al*. 2008). Peptide mixture from flaxseed with high levels of branched-chain amino acids, and low levels of aromatic amino acids have shown antioxidant properties by scavenging 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), and antihypertensive properties by inhibiting the ACE activity (Udenigwe and Aluko 2010).

Functional food

Functional foods are those that provide a specific health benefit to the consumer over and above their nutritional value. Functional foods are relatively recent developments that meet strengthening consumer demand for foods that enhance health and wellbeing. According to a new report by Global Industry Analysts, Inc. the global market for functional foods and drinks is projected to reach exceed $130 billion by the year 2015 (Global Industry Analysts 2010).

After reviewing various clinical studies regarding the health effects of flax elements, it can be concluded that flax in different forms can be consumed but the dietary intakes are equally important. The intended uses of whole and milled flaxseed are determined to be generally recognized as safe for

optimal health, many governments and public health authorities recommend increasing ω-3 fatty acids in the diet. In fact, as early as 1990, Health Canada recommended an ω-6: ω-3 fatty acid dietary ratio of 4:1 to 10:1 (Health and Welfare Canada 1990).

Supplemented products for clinical trials need to contain an amount and type of flaxseed that will significantly increase the levels of ALA in the blood over and above the recommended daily amount of 1.6 g/d for males and 1.1 g/d for females (Health Canada 2009; U.S. Department of Agriculture and U.S. Department of Health and Human Services 2010). Flaxseed contains approximately 23 g ALA per 100 g (USDA 2010) and thus, the recommended dietary amounts can be obtained by consuming about 9 g of flaxseed per day. Flaxseed is regaining its status as a functional food after centuries of use as natural medicine. Flaxseeds can be used as roasted and milled seeds, while flaxseed oil can be used in various food formulations in the form of neat oils, stable emulsions, and micro-and nano-encapsulated powder.

Flax or flaxseed oil has been incorporated into baked foods (Payne 2000; Pohjanheimo *et al*. 2006), juices, milk and dairy products (Dodin *et al*. 2008; 2005; Ivanova *et al*. 2011), muffins (Ramcharitar *et al*. 2005; Aliani *et al*. 2011), dry pasta products (Sinha and Manthey 2008; Lee *et al*. 2004; Hall *et al*. 2005; Marconi and Carcea (2001), macaroni (Hall *et al*. 2005) and beef patties (Bilek and Turhan 2009). Table 3 depicts recent reports of various food products enriched with flaxseed products in various dietary products have been given.

Table-1: Nutrient profile of Flax seeds (values per 100 g dry basis) (USDA, 2016)

Energy (Kcal)	534	Zinc (mg)	4.34
Protein (g)	18.29	Vitamin C (mg)	0.6
Total lipid (fat) (g)	42.16	Thiamin (mg)	1.644
Carbohydrate, by difference (g)	28.88	Riboflavin (mg)	0.161
Fiber, total dietary (g)	27.3	Niacin (mg)	3.080
Calcium (mg)	255	Vitamin B-6 (mg)	0.473
Iron (mg)	5.73	Vitamin A (IU)	0.00
Magnesium (mg)	392	Vitamin E (mg)	0.31
Phosphorus (mg)	642	Fatty acids, total saturated (g)	3.663
Sodium (mg)	30	Fatty acids, total monounsaturated	7.527
		Fatty acids, total polyunsaturated (g)	28.730

Table -2: **Recent clinical reports showing lipid profile and other health effects of flaxseed consumption in a diet**

Experiment	Model system	Significant findings	References
40 g/day of ground flaxseed-containing baked products were fed for 10 weeks	Human	Flaxseed significantly reduced LDL-cholesterol at 5 weeks (by 13 %), but not at 10 weeks (by 7 %) and lipoprotein by a net of 14 %. In men, flaxseed reduced HDL-Cholesterol by a net of 16 % and 9 % at 5 and 10 weeks, respectively	Bloedon *et al*. (2008)
Low-fat muffins supplemented with 500 mg flax lignan were fed for 6 weeks	Postmenopausal women	A significant decrease (0.88 to 0.80 mg/L) in C-reactive protein (CRP) was observed in test women	Hallund *et al.* (2008)
30 g/day of flaxseeds were consumed in diet for a period of 3 months	Hypercholesterolemic postmenopausal women	Dietary flaxseed supplementation lowered the total and LDL-cholesterol level, approximately by 7 % and 10 %, respectively. However, the levels of HDL and triglyceride remained unaltered	Patade *et al.* (2008)
Consumption of 5 g of flaxseed gums per day for 3 months	Type-2 diabetics	Total and LDL-cholesterol were reduced by 10 and 16 %, respectively.	Thakur *et al*. (2009)
Flaxseeds were consumed to see its effect on appetite -regulating hormones; lipemia and glycemia.	Young men	Decreased triglyceride levels (postprandial lipemia), Higher mean- ratings of satiety and fullness	Kristensen *et al*. (2011)
Flaxseed powder (60 g/day, 10 g ALA) was administered in a double blind routine for 12 weeks	Obese population	Total cholesterol level decreased from 197.2 to 179.4 mg/dl. LDL & HDL decreased from 122.3 & 50.9 to 106.6 & 47.9 mg/dl, respectively. While, VLDL increased from 25.8 to 26.6 mg/dl	Faintuch *et al*. (2011)
Consumption of 5 g of flax fibres daily for 1 week in form of bread and drinks	Young healthy adults	Faecal excretion of fat increased by 50 %. Flax bread and Flax drink reduced the Total & the LDL-cholesterol by 7 & 9 and 12 & 15 %, respectively.	Kristensen *et al*. (2012)
15 % flaxseed meal enriched biscuits were fed for 8 weeks	Hypercholesterolemic rats	Cholesterol & triglyceride level decreased from 456.66 & 173.84 to 183.92 & 102.67 mg/dl,respectively. LDL and VLDL decreased from 199.46 & 34.95 to 84.08 & 20.53 mg/dl, respectively.	Hassan *et al*. (2012)

		While, HDL increased from38.95 to 64.37 mg/dl.	
Flaxseed powder enriched diets were consumed for 12-weeks to check body weight and lipid profile	Rats	Rats fed with high fat & high fructose diet along with 0.02 % flax powder showed decreased levels of TG, total cholesterol and LDL cholesterol from 100, 69, and 10 to 96, 63 and 9 mg/dl, respectively	Park and Velasquez (2012)
Full fatty and partially defatted flaxseed flour @ concentration of 4-20 % supplemented diet was fed for 1 week in form of unleavened flatbread	Albino rat	12 % full fat & 16 % defatted flaxseed flour increased TD from 79.4 to 81.45 & 84.6; NPU from 44.3 to 49.4 & 54.65; PER from 1.51 to 1.8 & 1.87; and BV from 55.79 to 60.65 & 64.6	Hussain *et al.* (2012)

Table-3: Recent reports of various food products enriched with whole flaxseed, flax flour, and flax oil

Consumed flax form	Amount supplemented	Flax enriched food product	Main results	References
Ground flaxseed	7.3, 11.6 & 15.5 %	Muffins	Control muffin had higher score than the flax muffin for appearance, colour, flavour, texture, overall acceptability & food acceptance. Flaxseed muffin (11.6 %) was "neither liked nor disliked" to "liked slightly" in overall acceptability	Ramcharitar *et al*. (2005)
Flaxseed oil	0–12 %	Ice cream	Flax-ice cream showed minimal fat flocculation, less stabilisation of air cells resulting in a soft ice cream that had a high meltdown rate. Incorporation of 2 % flaxseed oil in a 12 % (w/w) ice cream was possible affecting the ice cream functionality	Goh *et al*. (2006
Milled flaxseed (Flour)	15 & 25 %	Yeast bread	Highest taste& aroma acceptance scores were found for yeast bread with 15 % flax bread. No significant increase in peroxide value was observed with 25 % flax bread till bread staling	Mentes *et al*. (2008)
Flax flour	15 %	Bread	Musty aroma was significantly reduced in flax bread during 4 weeks of storage with addition of Vitamin C, BHA & BHT	Conforti and Cachaper (2009)
Flaxseed oil (powder)	1, 2.5, 5.0 & 10 %	Bread	Water absorption capacity increased from 62 (control) to 70 % (10 % flax-bread). No effects on sensorial properties were observed	Gokmen *et al*. (2011)
Flax flour	Not available	Muffins & Snack bar	Flax muffins & snack bar showed lower acceptability than non-flax products. However, flavouring enhanced the overall acceptability significantly	Aliani *et al*. (2011)
Flaxseed cake	10 & 15 %	Brown bread	Bread samples with inclusion levels of 10 and 15 % flaxseed oil cake were acceptable to the consumer sensory panel.	Ogunronbi *et al*. (2011)
Flaxseed oil	1 %	Cheese	High retention of flax oil (5.2 mg/g) was observed in cheese without affecting the shelf life of the product	Aguirre and Canovas (2012)
Flaxseed oil	25, 50, 75 & 100 %	Shortening & biscuits	Biscuits made with 100 % substituted shortening were acceptable as control	Hassan *et al.* (2012)
Flax flour	16 % Corn snacks	16 % Corn snacks	7 fold increase in dietary fibres, almost 100 % increase in protein content, with similar acceptability score when compared to control	Trevisan and Areas (2012)
Milled flaxseed	23 %	Bagels	Flax aroma & flavours were detected in fortified bagels as compared to non-fortified bagels, but still were acceptable	Aliani *et al*. (2012)
Full fat and partially defatted flaxseed flour	4–20 %	Unleavened flat bread	12 % full fat and 16 % defatted flaxseed flour enriched bread showed maximum acceptability. The level of soluble, insoluble and total dietary fibres and essential amino acids were higher in flax flour enriched bread than control	Hussain *et al.* (2012)
Flaxseed flour	0–18 %	Cookies	Cookie dough stickiness significantly decreased with flaxseed flour. The 18 % flaxseed cookies had the firmest texture & darkest colour, unacceptable by consumers. While 6 & 12 % flaxseed cookies were acceptable without negatively affecting the physical and sensory properties	Khouryieh and Aramouni (2012)

CONCLUSION

To reduce the increasing burden on the health care system by a continuous preventive mechanism functional foods and nutraceuticals may provide a natural resource from plants. A large number of phytochemicals and bioactive have existed in foods of plant origin. Plant foods as medicines are assuming greater importance in the primary health care of individuals and communities in many underdeveloped, developing, and developed as well as developing countries. Flax as a whole is medicinally as well as dietary important for the human being. The biological activity is known for ages. The most worked out biological activity is related to ALA, lignans, and soluble polysaccharides. Most of the human diet and health studies to date show beneficial effects have used whole flaxseed, seed flour, linseed oil, and defatted flaxseed meal in various forms. Still, there is huge scope for economic extraction, modifications, and clinical evaluation of various phytoconstituents to make it a true functional food and dietary supplement. Various clinical studies discovered that the flaxseed constituents provide disease preventive and therapeutic benefits. This encourages the development of new branded healthy and functional foods using flaxseeds, oil, and cakes. As very little attention has been given to numerous unknown phytoconstituents of flax as a whole. Although, the specific phytochemicals responsible for human physiological effects are warranted even after synergistic effects of flax seeds in numerous forms. While cardiovascular disease and cancer are probably the best-researched areas that have shown substantial evidence of a beneficial action for dietary flaxseed, other areas like gastrointestinal health and diabetes have also been receptive to the beneficial effects of dietary flaxseed. Additional areas for human health require further research to make conclusive inferences but the preliminary data is encouraging. With little or no evidence of toxicity for dietary supplementation with flaxseed, there appears to be a clear argument to support its inclusion in the daily diet and little reason to oppose it. Therefore, we here suggest that the therapeutic effects of flaxseed components for disease prevention, health protection, and functional food and food supplement should be studied in detail. Over and above, detailed research is needed to develop quick, reproducible, and cost-effective practices for developing value-added flax seed enriched products.

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