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Recent advances in utilization of flaxseed as potential source for value addition

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Abstract – Flax seed (*Linum usitatissimum*) is an important oilseed crop which has gained importance since last few decades due to its unique nutrient profile. Flax seed comprises high amount of fiber and is a significant source of α-linolenic acid in the diet of vegetarian people. It is evident from several studies conducted that flaxseed carries functional ingredients and provide health benefits. Omega-3 fatty acid, lignan and dietary fiber are major bioactive components of flaxseed which can be delivered through value added products. Flax seed has been successfully exploited in preparation of various value added products. Commercially, all parts of flaxseed plant are exploited directly or after processing. Flaxseed consumption in the diet prevents serious diseases like coronary diseases, cancer, diabetes, obesity, gastrointestinal, renal and bone disorders. To the best of our knowledge, very limited review reports are available for commercial utilization of flaxseed in preparation of various value added products (bakery, dairy, extruded, snack, fermented and other traditional) and effect of flaxseed fortification on nutritional, physicochemical, phytochemical and sensory properties of these products. In future, this data could be useful for different food processing industries.

Keywords: flaxseed / health benefits / functional food / nutraceutical properties / value addition

Résumé – Les progrès récents dans l'utilisation de la graine de lin comme source potentielle de valeur ajoutée. La graine de lin (*Linum usitatissimum*) est une culture oléagineuse qui a pris de l'importance depuis quelques décennies en raison de son profil nutritionnel unique. La graine de lin contient une grande quantité de fibres et constitue une source importante d'acide α-linolénique dans l'alimentation des végétariens. Plusieurs études mettent en évidence que les graines de lin apportent des ingrédients fonctionnels et offrent des bénéfices santé. Les acides gras oméga-3, les lignanes et les fibres alimentaires sont des composants bioactifs majeurs des graines de lin qui peuvent être apportés *via* des produits à valeur ajoutée. La graine de lin a été exploitée avec succès dans la préparation de divers produits à valeur ajoutée. Commercialement, toutes les parties de la graine de lin sont exploitées directement ou après traitement. La consommation de graines de lin dans le régime alimentaire prévient certaines maladies graves comme les maladies coronariennes, le cancer, le diabète, l'obésité, les troubles gastro-intestinaux, rénaux et osseux. À notre connaissance, un nombre limité de revues fait le point sur l'utilisation commerciale de la graine de lin en préparation de divers produits à valeur ajoutée (de boulangerie, laitiers, extrudés, collations, fermentés et autres traditionnels) et sur les effets de l'enrichissement du lin sur le plan nutritionnel, physico-chimique, phytochimique et les propriétés sensorielles de ces produits. À l'avenir, ces données pourraient être utiles pour différentes industries de transformation des aliments.

Mots clés : graine de lin / bénéfices santé / alimentation fonctionnelle / propriétés nutraceutiques / valeur ajoutée

1 Introduction

Flax seed (*Linum usitatissimum*) commonly known as linseed is a member of the genus Linum in the family Linaceae. Flax is an oldest agronomic crop having more than 300 species and which are cultivated for food and fiber since ancient times. Flax seed is recognized either by variety or by color (brown and yellow). Brown colored flaxseed is the most common and high in alpha-linolenic acid, while there are two types of yellow colored flaxseed: Omega and Linola (Conforti and Cachaper, 2009). Top most producer of flaxseed in the world is

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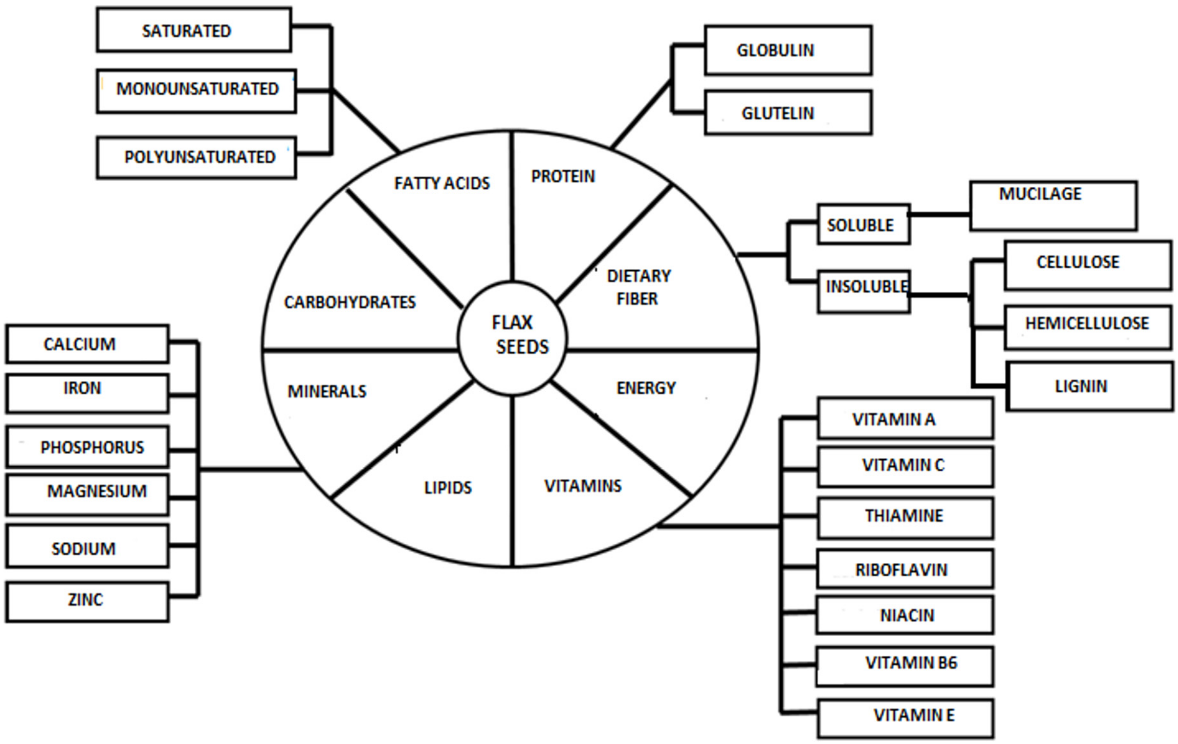

Fig. 1. Nutritional profile of flax seed.

Canada with 0.81 million tons in 2014–2015 (Flax Council of Canada, 2015). Flax seed is cultivated in many parts of world for fiber, oil as well as for medicinal purposes and also as a nutritional product (Kajla *et al.*, 2015). Demand for flaxseed has been increased because of consumer awareness about the relationship between diet and health. Flaxseed is considered as a potential functional food ingredient as it provides various health benefits along with nutritional value (Eyres, 2015).

However, it is an underutilized crop, but gained importance in the last few decades since it has a unique nutrient profile, particularly omega-3 fatty acid, lignans, and fiber (Goyal *et al.*, 2014). Flax seed is an important source of α-linolenic acid in the diet of vegetarian people. Therefore, it may serve as an alternate for supplying fatty acid to populations which do not have large access to seafoods (El-Beltagi *et al.*, 2007). The total protein content in flaxseed ranges between 20 to 30% composed of mainly 80% globulins and 20% glutelin (Hall *et al.*, 2006). The amino acid pattern of flax protein is similar to that of soybean protein, which is viewed as one of the most nutritious of the plant proteins (Morris, 2007). Based on a proximate analysis conducted by the Canadian Grain Commission flax is rich in fat, protein and dietary fiber. An analysis of brown Canadian flax averaged 41% fat, 20% protein, 28% total dietary fiber, 7.7% moisture and 3.4% ash (Morris, 2007). Cellulose, hemicellulose and lignin are insoluble fiber constituents abundantly found in flaxseed while mucilage gums form the soluble fiber fraction (Morris, 2007). Major lignan present in flaxseed is secoisolariciresinol diglycoside (SDG). Flax seed is an equally good source of minerals, particularly, phosphorus, magnesium, calcium, iron, zinc and very little amount of sodium. Flax seeds also contain anti-nutrients which may pose adverse health effects and may influence the well-being of human population. Major anti-nutrients in whole flaxseed are cyanogenic glycosides (250–550 mg/100 g) (Singh *et al.*, 2011), while the phytic acid content of flaxseed meal is 2.3–3.3% which result in decreased absorption of nutrients. Hydrogen cyanide released from flaxseed is minimal and lower than the toxic or lethal dose. The release of hydrogen cyanide is approximately 5–10 mg from 1–2 tablespoons (recommended daily intake of flaxseed). This value is much lower than the acute toxic dose which is estimated to be 50–60 mg. Also, human beings can detoxify cyanide levels below 30–100 mg/day (Roseling, 1994). Roasting is generally done to remove cyanogenetic glycosides. Wanasundara *et al.* (1993) described a method for elimination of cyanogenetic glycosides from flaxseed meal in which solvent extraction consisting two phases *i.e.*, hexanes and alkanol was used either with the addition or without water or ammonia. The alkanol could be methanol, ethanol or isopropanol. By utilizing methanol solutions, more than 90% of the cyanogenetic glycosides *viz.* linustatin and neolinustatin were removed. Proximate composition and antinutrient content vary with varietal differences (Kajla and Sharma, 2016). Nutritional profiles of flaxseed are reported in Figure 1. It is evident from the data reported in Table 1 that flaxseed contains the second highest amount of protein (18.29%) followed by sesame seeds (17.73%), chia seed (16.54%) and safflower seeds (16.18%). Fiber content in flaxseeds (27.3%) is more than sesame seeds (11.8%) and sunflower seed kernels (8.6%). Also, polyunsaturated fatty acid is present in highest amounts (28.73%) in flaxseed when compared with other oilseeds as presented in Table 1. Along with that flaxseed is also a good source of B-vitamins (USDA, 2016).

Table 1. Nutritional profile of various oilseeds (values per 100 g dry basis) (USDA May, 2016 report).

Nutrient	Flaxseeds	Chia seeds	Sesame seeds	Safflower seeds	Sunflower seed kernels
Energy (Kcal)	534	486	573	517	584
Protein (g)	18.29	16.54	17.73	16.18	20.78
Total lipid (fat) (g)	42.16	30.74	49.67	38.45	51.46
Carbohydrate, by difference (g)	28.88	42.12	23.45	34.29	20.00
Fiber, total dietary (g)	27.3	34.4	11.8	–	8.6
Calcium (mg)	255	631	975	78	78
Iron (mg)	5.73	7.72	14.55	4.90	5.25
Magnesium (mg)	392	335	351	353	325
Phosphorus (mg)	642	860	629	644	660
Sodium (mg)	30	16	11	3	9
Zinc (mg)	4.34	4.58	7.75	5.05	5.00
Vitamin C (mg)	0.6	1.6	0.0	0	1.4
Thiamin (mg)	1.644	0.620	0.791	1.163	1.480
Riboflavin (mg)	0.161	0.170	0.247	0.415	0.355
Niacin (mg)	3.080	8.830	4.515	2.284	8.335
Vitamin B-6 (mg)	0.473	–	0.790	1.170	1.345
Vitamin A (IU)	0.00	54	9	50	50
Vitamin E (mg)	0.31	0.50	0.25	–	35.17
Fatty acids, total saturated (g)	3.663	3.330	6.957	3.682	4.455
Fatty acids, total monounsaturated	7.527	2.309	18.759	4.848	18.528
Fatty acids, total polyunsaturated (g)	28.730	23.665	21.773	28.223	23.137

1.1 Health benefits of flaxseed

Functional ingredients present in flaxseed make it beneficial for critical diseases like cardiovascular diseases, cancer, diabetes, obesity, renal and bone disorders (Katare *et al.*, 2012). Dietary flaxseed modifies cardiovascular risk factor by improving lipid profile in hyperlipidemic patients. *In vivo* studies conducted on rats indicated that flaxseed has the ability to protect from breast, colon and ovarian cancer by preventing the formation of tumor and additionally diminishing blood vessel cell development (Truan *et al.*, 2012). High content of SDG lignin in flaxseed is possibly responsible for a breast tumor-reducing effect (Chen *et al.*, 2011). Flaxseed has a protective effect against diabetes risk due to presence of dietary fiber, lignan, and ω-3 fatty acid (Adlercreutz, 2007).

Kapoor *et al.* (2011) observed that postprandial blood glucose was decreased by 7.9 and 19.1%, respectively, by supplementation of flaxseed powder (15 and 20 g/day) for 2 months in diabetic females. Non-starch dietary fibers of flaxseed delay stomach emptying and decrease absorption of nutrients in the small intestine. Thus, it can prevent obesity-related diseases (Singh *et al.*, 2011). Effects of flax fiber on gastrointestinal motility, constipation, glucose tolerance, hypocholesterolemic effect and fermentation have been described comprehensively in various reviews and articles (Mani *et al.*, 2011; Kristensen *et al.*, 2012, 2013).

Omega-3 fatty acids possess anti-inflammatory properties so they protect the destruction of kidneys in adults. More consumption of omega-3 polyunsaturated fatty acid reduced occurrence of chronic kidney diseases (Gopinath *et al.*, 2011). Dietary flaxseeds have ability to increase blood levels of ALA, even when incorporated into baked goods like breads or muffins in ground or milled form.

2 Value added products prepared by incorporation of flax seed

Value added products are prepared for enhancing the value of food items through the addition of ingredient, processing or packaging. Value added food products are more attractive and usable by the consumer than original commodity. Some examples of value added products are breakfast cereals, skim milk, ice cream, yogurt, cheeses, extruded snacks, etc.

Thompson and Cunnane (2003) provided the current status of the knowledge about the analysis and composition of flaxseed, the metabolism and bioavailability of its major components, the effect of flaxseed on development and disease, processing of flaxseed, and availability of flaxseed products which created interest amongst consumer and food industry about flax seed as a beneficial component in the human diet. Commercially, all parts of flaxseed plant are exploited directly or after processing in preparation of various value added products. When flax is consumed by humans, then it is usually described as flaxseed whereas when it is used for industrial purposes, then it is described as linseed (Morris, 2007). As a functional food ingredient, flaxseed (milled or ground) and flaxseed oil has been incorporated into baked (Tab. 2), dairy (Tab. 3), extruded (Tab. 4), snacks and other products (Tab. 5). Commercial use of flax in various food products is presented in this review.

Table 2. Baked products prepared by flaxseed fortification in different forms and at different concentrations.

Product name	Flaxseed form	Amount of supplementation (%)	Reference
Bagels	Milled flaxseed	23	Aliani *et al.*, 2012
Bagels/pretzel-type bakery product	Flaxseed flour	5–15	Alpaslan and Hayta, 2006
Bread	Flaxseed flour	15	Conforti and Cachaper, 2009
Bread	Raw and roasted ground flaxseed	5–15	Marpalle *et al.*, 2014
Chinese steamed bread	Flaxseed hull extracts	1	Hao and Beta, 2012
Yeast bread	Milled flaxseed (flour)	15–25	Mentes *et al.*, 2008
Taftoon bread	Coated and uncoated ground flaxseed	5–25	Roozegar *et al.*, 2015
Bread	Flaxseed flour	15–30	Lipilina and Ganji, 2009
Pan bread	Roasted flaxseed flour	10–20	Ahmed *et al.*, 2010
Unleavened flat bread	Full fat and partially defatted flaxseed flour	4–20	Hussain *et al.*, 2012
Pita bread	Flaxseed cake flour	5–20	Khattab *et al.*, 2012
Cereal bars	Flaxseed flour	6–18	Khouryieh and Aramouni, 2013
Biscuits	Flaxseed flour	11–43	Masoodi and Bashir, 2012
Biscuits	Flaxseed meal and oil	15 and 100	Hassan *et al.*, 2012
Biscuits	Flaxseed flour	20–40	Rathi and Mogra, 2012
Biscuits	Flaxseed flour	5–15	Patil *et al.*, 2013
Sugar snap cookies	Barley, flaxseed, oats and soya bean flour blend	10–20	Rajiv and Soumya, 2015
Cookies	Roasted flaxseed flour	5–30	Ganorkar and Jain, 2014
Cookies	Flaxseed oil	5–50	Rangrej *et al.*, 2015
Cookies	Flaxseed flour	0–18	Khouryieh and Aramouni, 2012
Cookies	Roasted flaxseed flour	5–20	Rajiv and Soumya, 2015
Cake and Cookies	Flaxseed flour	5–25	Bashir *et al.*, 2006
Carrot cake (gluten-free)	Flaxseed meal	9.48	Gambus *et al.*, 2009
Cake	Flaxseed flour	5–45	Moraes *et al.*, 2010
Muffins	Ground flaxseed	7.3–15.5	Ramcharitar *et al.*, 2005
Muffins	Raw and roasted flaxseed flour	10–40	Sudha *et al.*, 2010
Muffins	Flaxseed flour	33–66	Lipilina and Ganji, 2009
Muffins	Flaxseed meal	2–5	Shearer and Davies, 2005
Pizza	Roasted flaxseed flour	10–20	Ahmed *et al.*, 2010

Table 3. Dairy products prepared by flaxseed fortification in different forms and at different concentrations.

Product name	Flaxseed form	Processing method	Amount of supplementation	Reference
Dahi (Indian Yogurt)	Microencapsulated flaxseed oil powder (MEFOP)	Fermentation	1–3%	Goyal *et al.*, 2016
Ice cream	Flaxseed oil	Freezing	0–12%	Goh *et al.*, 2006
Cheese	Flaxseed lignan (SDG)	Pasteurization and fermentation	1 g/10 L	Hyvarinen *et al.*, 2006
Yogurt	Flaxseed lignan (SDG)	Fermentation	100 mg	Hyvarinen *et al.*, 2006
Milk	Flaxseed lignan (SDG)	Heat treatment	1%	Hyvarinen *et al.*, 2006
Whey drinks	Flaxseed lignan (SDG)	Pasteurization	10 mg/100 ml	Hyvarinen *et al.*, 2006
Butter	Flaxseed additive	–	0.8–1.6%	Ivanov *et al.*, 2011

2.1 Bakery products

The baking industry is one of the leading systematized processed food industry. Bakery products are popular due to their convenience, low price and ready-to-eat nature, easy transportation, availability in numerous tastes and textural profiles. The foremost benefit of bakery products is docility for fortification with cereals, millets or other ingredients (Gat and Ananthanarayan, 2015a, b). Therefore, these products are an effective medium for delivering functional ingredients to consumers. Commercially available cookies are mostly deficient in ALA and dietary fiber (Ganorkar and Jain, 2014). Refined ingredient usage makes biscuits deprive of grain components that are protective of health (Fardet, 2010).

Flax seed can be incorporated into baked good as whole, milled, ground, roasted and in the form of oil. Flaxseed addition in bakery products has been a challenge for various researches due to oxidative instability of flaxseed at high

Table 4. Extruded products prepared by flaxseed fortification in different forms and at different concentrations.

Product name	Flaxseed form	Amount of supplementation	Reference
Extruded noodle	Flaxseed flour	10%	Bhise *et al.*, 2014
Macaroni	Ground whole flaxseed and ground flaxseed hull	15%	Lee *et al.*, 2004
Pasta	Flaxseed flour	15%	Manthey *et al.*, 2008
Pasta	Flaxseed flour	5–20%	Sinha and Manthey, 2008
Pasta	Defatted Milled Flaxseed	10 and 30 g	
Puffs	Flaxseed with corn meal	15%	Wu *et al.*, 2007
Corn and flaxseed snacks	Flaxseed flour	16%	Trevisan and Arêas, 2012
Extruded snacks	Flaxseed flour	0–20%	Mesquita *et al.*, 2013
Bean snack	Milled flaxseed	5–20%	Vadukapuram *et al.*, 2014
Spaghetti	Ground flaxseed	5–15%	Manthey *et al.*, 2002
Cereal Based products	Flaxseed meal	9%	Giacomino *et al.*, 2013

Table 5. Other traditional products prepared by flaxseed fortification in different forms and at different concentrations.

Product name	Flaxseed form	Processing method	Amount of supplementation (%)	Reference
Chutney powder	Flaxseed flour	–	50	Rao *et al.*, 2011
Vegetable chilla	Flaxseed flour	Shallow frying	20–40	Rathi and Mogra, 2012
Wheat chips	Flaxseed flour	Frying	10–20	Yuksel *et al.*, 2014
Energy bar	Flaxseed flour	Freezing	0–20	Mridula *et al.*, 2013
Vegetable soup	Flaxseeds	–	15	Jain *et al.*, 2014
Bhelpuri chat	Flaxseeds	–	10	Jain *et al.*, 2014
Vermicelli	Flaxseeds	–	10	Jain *et al.*, 2014
Dry-fermented sausages	Flaxseed oil	Fermentation	3.3	Ansorena and Astiasarán, 2004
Tahina	Roasted flaxseed flour	Grinding and mixing	25–100	Ahmed *et al.*, 2010
Manchurian	Flaxseed flour	Shallow frying	20–40	Rathi and Mogra, 2012

temperatures and during storage. Recent studies have suggested that flaxseed has been used in various bakery products like bagels, breads, biscuits, cookies, muffins, pizza, buns and patties at different levels (Kaur *et al.*, 2017) (Tab. 2).

Addition of flax seeds into various bakeries and other cereal products gave positive results for enhancing overall nutritional quality. Incorporation of 10 g flaxseed per 100 g refined flour into functional bread resulted in an increase in water absorption, dough stickiness and crumb softness (Marpalle *et al.*, 2014). Tafton bread with 5 and 15% coated ground flaxseed with arabic gum or hydrogenated fat had acceptable rheological and organoleptic characteristics (Roozegar *et al.*, 2015). Flaxseed muffins (7.3%, 11.6% and 15.5%) were less acceptable than control muffins on the basis of sensory parameters, but they provide 16% of the dietary fiber requirement (Ramcharitar *et al.*, 2005). Flaxseed cookies (6 and 12%) were accepted by the consumer without adversely affecting physical and sensory quality (Khouryieh and Aramouni, 2012). Shortening can be replaced with flaxseed oil up to 30% in cookies and it enhances ω-3 fatty acid by 14.14% in flaxseed oil cookies (Rangrej *et al.*, 2014). Chemical evaluation of some products (pan bread-pizza-Tahina) showed that protein content, fat, fiber, and ash content increased with addition of flaxseed to wheat flour by 15% while carbohydrate decreased in bread and pizza (Ahmed *et al.*, 2010).

2.2 Dairy products

Dairy-based products are a major part of functional foods. Functionality of dairy products can be developed and designed simply by modifying and/or enriching healthy nature of the original base. Type of milk and culture, the amount of milk fat and nonfat milk solids, fermentation and temperature used affect aroma, body and flavor of cultured dairy products. Milk and milk products have been proven to be a successful medium for delivering bioactive ingredients (Rowan *et al.*, 2005). Value-added dairy products include low-lactose or lactose-free products, hypoallergenic formulations with hydrolyzed protein for milk-hypersensitive infants, milk enriched with calcium, vitamins, etc. (Ozer and Kirmaci, 2010). Flaxseed oil and flaxseed lignan have also been supplemented into milk and various dairy products such as ice cream, cheese, yogurt, whey drinks and butter (Tab. 3). 2% (w/w) flaxseed oil in a 12% (w/w) ice cream mix can be incorporated without significantly affecting the overall functionality of ice cream. SDG added to milk, yogurt, and cheese were found to withstand high-temperature pasteurization, fermentation, and milk renneting processes well (Hyvarinen *et al.*, 2006). Microencapsulated flaxseed oil powder was fortified in *dahi* (Indian yoghurt) at three different formulations as 1, 2 and 3%, which could serve as a potential delivery system of omega-3 fatty acids (Goyal *et al.*, 2016).

2.3 Extruded products

Extrusion cooking technology plays a key role in many food-processing industries as a continuous cooking, mixing, shearing and forming process (Ananthanarayan *et al.*, 2017). It can be used to produce a number of foods and feed applications such as snacks, ready to eat (RTE) cereals, confectionery products and crisp breads. Convenience, value, attractive appearance and particular texture of extruded foods are the main reason of consumer acceptance of these foods (Anton *et al.*, 2009).

Some extruded products prepared by flaxseed fortification are presented in Table 4. An extruded flaxseed-containing product that can be consumed as a breakfast cereal or snack may encourage consumption of flaxseed and provide health benefits for consumers (Wu *et al.*, 2007). Manthey *et al.* (2008), Sinha and Manthey (2008), Gupta (2012) have developed flaxseed-based pasta which ensures functional properties of flaxseed. Under conditions of 10% flaxseed flour, 230 rpm screw speed, temperature of 90 °C and moisture of 12% an expanded snack product with good physical properties can be obtained (Mesquita *et al.*, 2013). Vadukapuram *et al.* (2014) reported that in extruded bean snack, omega-3 fatty acids and bulk density, improved with increasing concentration of flaxseed (5–20%). Similar results were represented by Giacomino *et al.* (2013) in cereal bars, enriched with an extruded flax seed meal which provide an adequate nutritional quality of proteins, dietary fiber and ω6:ω3 ratio. With incorporation of 10% flaxseed flour for the preparation of extruded noodles indicated improvement in protein content, but as the level of flaxseed flour increased it shows the negative effect on sensory, color and cooking characteristics of noodles (Bhise *et al.*, 2014).

2.4 Snack products

A snack is part of the food typically eaten in between meals, but not as a substitute for a meal. Snacks provide considerably less calories than would be consumed in a typical meal. Conventionally, snacks are prepared from ingredients such as cold cuts, fruit, leftovers, nuts and sandwiches, etc. Processed snack foods are convenience food and less perishable than prepared foods. They often contain sweeteners, preservatives, and appealing ingredients such as chocolate, peanuts, and specially-designed flavors (for example flavored potato chips). In recent years, interest of the snack food industry towards developing new products to attract consumers has increased (Meethal *et al.*, 2017). Addition of flaxseed (10%) resulted in an increase of omega-3 fatty acids and protein of wheat chips samples and overall acceptability of chips increased with increase of frying temperature (Yuksel *et al.*, 2014).

Addition of reddish brown flax seeds into snacks enhances texture and gives a superior taste along with a pleasant nutty flavor (Manthey *et al.*, 2002). Moreover, flax seeds have a healthy lipid profile which alters the lipid content of snack products and modify omega-3 polyunsaturated fatty acid profile. Thus, it improves the nutritional quality of these snacks and reduces risk of chronic maladies in the community (Ansorena and Astiasarán, 2004). A snack made with flaxseed and corn showed a sevenfold increase in dietary fiber, 100% increase in protein content and was as acceptable as commercial corn snacks (Trevisan and Arêas, 2011).

2.5 Fermented products

Fermentation, also called souring, is a traditional preservation method, which can be used to improve the shelf life and digestibility of the products (Chavan *et al.*, 2018). Fermented cereal products containing live lactic acid bacteria are known and fermentation of flaxseed-based material is suggested due to its advantageous effects. Crushed or crushed and milled flaxseed is supplemented with other cereals or plant seeds, *e.g.* oat, buckwheat or soy to prepare flaxseed-based fermented products.

Among existing beverage matrices, fruits/vegetable juice matrix is noted to be a popular format in the fast moving consumer goods section. Solubility, hydration rate, and thickening properties of ground flaxseed are important considerations when adding flaxseed to beverages. Flaxseed-based fermented beverages can be prepared with the help of lactic acid fermentation of flaxseed suspension, which is further seasoned with the help of different fruit/vegetable juice blends. Further, aroma and flavor of such fermented beverages is improved with the help of different natural and artificial flavor extracts. Texture and rheological structure of flaxseed-based fermented products can be improved with the addition of different additives. Cloud stability and the juice turbidity of carrot juice were lowered, with the addition of flaxseed gum as a hydrocolloid at different concentrations, which abolish creamy appearance (Shakeel *et al.*, 2015). The formation of stable emulsion is the major problem while preparing flaxseed oil enriched beverages. One of the recent research study report on the formation of stable emulsions of flaxseed oil (1 % v/v) in carrot juice using 20 kHz ultrasound at 176 W and 4 min of processing time (Shanmugam and Ashokkumar, 2014).

2.6 Other traditional products

Rathi and Mogra (2012) tried traditional snacks, chapatti, khakhra, vegetable chilla and manchurian by supplementation of flaxseed flour at different levels (Tab. 5). Appetizer, starter and precooked food recipes *viz.* vegetable soup, vermicelli and bhelpuri chat prepared with the incorporation of flax seeds had good nutritional and functional properties. Also, these low fat recipes are good to maintain a healthy heart (Jain *et al.*, 2014). Flax chutney powder, a palatable functional food adjunct, was prepared by mixing roasted and powdered flax seeds with other selected spice ingredients which is having high nutraceutical properties (Rao *et al.*, 2011). Also, flaxseed flour can be used as a functional ingredient to enrich traditional animal origin products such as beef patties which has increased the energy value as well as polyunsaturated/saturated fatty acid ratio (Bilek and Turhan, 2009).

3 Effects of flaxseed fortification on different properties of value added products

3.1 Nutritional properties

Balanced diet is vital for good health and well-being. The food delivers energy, protein, fat, vitamins and minerals for living, growth and to work properly. Wide variety of different foods is required to provide precise amounts of nutrients for good health. Unhealthy eating habits are the leading cause of death and increased risk of numerous diseases. Diet and nutrition play an important role in critical ailments such as coronary heart diseases, obesity, cancer, type-2 diabetes, bone disorders, dental caries, gall bladder disease, dementia and nutritional anemia.

Flaxseed flour greatly enhanced nutritional qualities without affecting the overall acceptability of products. Ash, protein, fat and crude fiber contents of flaxseed cookies and biscuits were more than control which could be accounted by the fact that flaxseed is far higher in mineral, fat, protein and fiber content than wheat flour (Patil *et al.*, 2013; Masoodi and Bashir, 2012). Sudha *et al.* (2010) and Bashir *et al.* (2006) reported similar results for flaxseed incorporated muffins; cookies and cakes respectively. Fortification of biscuits with flaxseed flour resulted in decreased carbohydrate content as compared to control (Masoodi and Bashir, 2012). Results indicated that flaxseed flour incorporation considerably enhanced nutritional quality, particularly protein, fat, crude fiber, iron, calories and omega-3 content of cereal and energy bars (up to 12% and 5–20%, respectively) without affecting their sensory and quality properties (Khouryieh and Aramouni, 2013; Mridula *et al.*, 2013).

The major benefit of flax seed enrichment is generally an increase in omega-3 fatty acid content of products. Flax seed oil enriched biscuits were particularly rich in alpha linolenic acid (42.76%) and they contained a less amount of linoleic acid (13.52%) (Hassan *et al.*, 2012). Rangrej *et al.* (2014) have also represented similar results that omega-3 fatty acid increased from 0 (control) to 14.14% with incorporation 30% flaxseed oil in cookies. Cakes and breads prepared with 30% flaxseed flour received claims of good and excellent source of dietary fiber and linolenic acid (Moraes *et al.*, 2010; Lipilina and Ganji, 2009).

As a baking ingredient, ground flaxseed does not lose significant amounts of ALA during baking (Ganorkar and Jain, 2014). Also, extruding, drying and cooking had little or no effect on stability of lipids in macaroni containing flaxseed (Lee *et al.*, 2004). This might be due to the high natural level of antioxidant active lignans, which contribute to the oxidative stability of flaxseed oil and products with incorporated flax seed. Levels of soluble, insoluble and total dietary fiber and essential amino acids were higher in unleavened flat bread with added flaxseed when compared with control (Hussain *et al.*, 2012). Trevisan and Arêas (2011) also represented similar results for corn-flaxseed snack which had a sevenfold increase in dietary fiber, almost 100% increase in protein content compared to pure corn snack.

3.2 Phytochemical properties

Many researchers have identified flaxseed as a new source of nutraceutical with desirable functional characteristics because of its high content of phytochemicals (Conforti and Cachaper, 2009). Consumers also now believe in health benefits or nutrition as one of the desirable food qualities. Among other materials, incorporation of flaxseed has been shown to cause a positive impact on levels of proteins and dietary fiber of cereal-based traditional products. Incorporation of flaxseed believed to promote utilization as well as increase the nutraceutical appeal of the processed food product. Antioxidant activity and total phenolic content of Chinese steamed bread containing barley, flaxseed, and barley-flaxseed hull extracts were increased compared to their control sample (Hao and Beta, 2012). Rao *et al.* (2011) prepared an Indian traditional product (chutney powder) containing 50% flaxseed powder and reported that the total phenol content of functional food adjunct increased with addition of flaxseed powder. Also, another researcher (Kaur and Das, 2014) reported similar observations of increases in phytochemical properties (total phenol content and antioxidant) with the incorporation of flaxseed in functional dry soup mix.

3.3 Physico-chemical properties

Physical properties are used to observe and describe matter without changing the composition of matter. In bakery product weight, diameter, thickness and spread ratio are important physical properties. While in case of extruded product expansion ratio, bulk density, water absorption and water solubility are important physical properties. Increasing levels of flaxseed flour resulted in greater thickness and increase in diameter than that of control biscuits and cookies, but spread ratio was significantly decreased (Ganorkar and Jain, 2014; Patil *et al.*, 2013; Hussain *et al.*, 2012). Whereas, Rangrej *et al.* (2014) observed that the increase in the flaxseed oil level increased spread ratio and breaking strength of cookies. Overall loaf volume of cakes decreased as the amount of flaxseed was increased in the treatment (Bashir *et al.*, 2006). Possible reason could be that gluten development was inhibited with increasing flaxseed level, therefore decrease in height was observed. Also, the high fat content of flaxseed flour causes less air entrapment (Khouryieh and Aramouni, 2012).

Mesquita *et al.* (2013) concluded that under the conditions of 10% flaxseed flour, 230 rpm screw speed, temperature of 90 °C and moisture of 12%, extruded snack products with good physical properties could be obtained. Ahmed (1999) reported that addition of flaxseed flour (5–20%) decreased expansion ratio and increased bulk density resulting a denser extruded corn-based flax snack product. In addition, extrudate became darker, and both water absorption and water solubility decreased with increasing flaxseed flour content.

Baked as well as extruded products have different risks in terms of the formation of thermal process contaminants. Particularly in breads, the temperature of the crust is approaching to oven temperature as soon as the moisture content decreases to a critical level. This makes the crust susceptible to form acrylamide during baking. Gokmen *et al.* (2011) reported that with the use of nanoencapsulated flax seed oil, it is possible to reduce the risk associated for acrylamide formation in bread. In addition, Anese *et al.* (2015) suggested that acrylamide formation was greater for the omega-3 enriched biscuits baked at ambient pressure than for samples cooked at reduced pressure. While Bartkiene *et al.* (2016) showed lactic acid fermentation as another way to reduce the amount of acrylamide in wheat biscuits supplemented with flaxseed and lupine.

3.4 Color properties

Color of food product is a key factor which influences customer selection. The first decision about a food's quality is most often taken by its appearance which includes color, shape, texture and other surface characteristics (Gat and Ananthanarayan, 2016). Color plays an important role in food choice in influencing taste thresholds, sweetness, perception, food preference, pleasantness and acceptability.

Flaxseeds have a significant effect on color scores *i.e.*, L* (lightness/darkness), a*(redness/greenness) and b*(yellowness/blueness) of various fortified food products. Color values of different flaxseed supplemented products like cookies (Ganorkar and Jain, 2014), muffins (Shearer and Davies, 2005), bars (Khouryieh and Aramouni, 2013), pasta (Sinha and Manthey, 2008) and extrudates (Vadukapuram *et al.*, 2014) were decreased. Flaxseed addition, significantly ($p < 0.05$) decreased lightness and increased redness of bars (Khouryieh and Aramouni, 2013). Increased flaxseed flour level in cookies led to considerably darker and browner appearance of cookies possibly due to Maillard browning reactions during cooking of flaxseed flour (Khouryieh and Aramouni, 2012).

3.5 Textural and rheological properties

Texture of foods comprises a complex group of physical properties that result from structural makeup of food. Texture plays a key role in consumer acceptance and market value of food products. Texture characteristics are important factors for the raw products and for processing, preparation, and consumption. Adhesiveness, chewiness, cohesiveness, consistency, crispiness, crunchiness, elasticity, extensibility, firmness, fracturability, gumminess, hardness, rupture strength, springiness, stiffness, stringiness and other parameters are important textural parameters.

Texture analysis of cookie doughs showed that there was a decrease in hardness and springiness values, whereas gumminess values increased by 10–20% multigrain powder containing flaxseed flour (Rajiv and Soumya, 2014). Rheological characteristics of different dough were investigated using farinograph and extensograph. Dough properties such as peak viscosity, dough stability, resistance to the extension and extensibility values were decreased with increase in substitution level (5–20%) of roasted ground flaxseed (Rajiv *et al.*, 2011).

Khattab *et al.* (2012) observed that defatted flaxseed flour incorporation (up to 15%) into pita bread had decreased moisture loss and increased alkaline water retention capacity and thus improved its textural characteristics without affecting physical and sensory properties. Whereas, after incorporation of 15% roasted flaxseed flour into control cookies an increasing hardness was observed by Ganorkar and Jain (2014).

The flax seed bread had a softer texture and lower staling rate comparisons to control bread (Roozegar *et al.*, 2015). Crumb softness of bread increased with increase in flaxseed flour level (Marpalle *et al.*, 2014). Goh *et al.* (2006) indicated that addition of flaxseed oil into ice cream resulted in a poor texture probably due to very low melting temperature ($< 12\,°C$) of flaxseed oil. Hardness values of wheat chips samples were decreased with increase of frying temperature because the addition of flaxseed flour increased dry matter and protein content of samples (Yuksel *et al.*, 2014).

3.6 Sensory properties

Sensory evaluation measure, analyze and interpret responses to products as perceived by the senses of sight, smell, touch, taste, and hearing. It is a scientific method which explores specific characteristics of an ingredient or food product by comparing similarities and differences in a range of products. Appearance, color, flavor, texture, odor, touch and temperature, etc. are sensory properties by which human responses to composition of food and drink are analyzed. At present, new challenges faced by the food industry are gradually transforming sensory to a more proactive role for producing new products based on unique sensory properties.

Studies have shown that increase in substitution level of flaxseed in different products has decreased sensory scores for different parameters as compared to standard products, but at a certain level it was acceptable (Ramcharitar *et al.*, 2005; Rangrej *et al.*, 2014; Masoodi and Bashir, 2012; Bashir *et al.*, 2006; Gambus *et al.*, 2009). Aliani *et al.* (2012) showed that bagels prepared by flaxseed incorporation were acceptable in terms of appearance, color, texture and flavor. Results of Patil *et al.* (2013) also indicated that biscuit containing 10% flaxseed had higher acceptability and there was no mark reduction in score for color, taste and appearance of biscuit.

Khouryieh and Aramouni (2013) observed that overall acceptability for both 12% flax bars and control was same at 9-point hedonic scale. Whereas Mridula *et al.* (2011) indicated that omega-3 fatty acid rich energy bar of acceptable quality could be prepared using 15% flaxseed and 45% sweeteners with other ingredients at commercial scale and also stored well for 90 days at refrigerated condition. Higher than 30% incorporation of flaxseed flour adversely affected the appearance of snack products, *i.e.* color and taste wise bitterness was detected by panel members (Rathi and Mogra, 2012). Flavor is the main criterion that makes the product to be liked or disliked. Flaxseed has a unique pleasant nutty flavor that compliments many combinations. Butter with flax seed additive had pure creamy flavor and odor without flavor and odor of additive, yellow color and good spread ratio as well as plasticity (Ivanov *et al.*, 2011).

4 Effect of flaxseed fortification on shelf-life of value added products

Ground or whole flax seed can be added to almost any baked product to add a nutty flavor to bread, waffles pancakes and other products. But the major cause of concern during storage is lipid oxidation, which is a major cause of loss of nutritional and sensory quality of processed foods. Lipid oxidation can be limited during processing, but it might increase during storage. Packaging under nitrogen or vacuum in opaque containers may further protect processed food during storage. In addition, external factors during storage such as temperature, light and oxygen exposure need to be considered while storing processed food products. In flaxseed incorporated food applications, however, quality factors such as the sensory attributes and the shelf stability of the targeted food product are important, since the highly unsaturated nature of the predominant fatty acid may lead to early rancidity and result in undesirable sensory taints.

Some of the researchers have demonstrated storage stability effect of flaxseed incorporated products such as the texture of the flaxseed cookies slight decreased (Rajiv *et al.*, 2011); the color of the flaxseed chutney powder retained well, and scores for the characteristic flavor decreased significantly (Rao *et al.*, 2011); flaxseed oil cookies showed higher increases in peroxide value as compared with the control cookies (Rangrej *et al.*, 2014); overall acceptability score for flavor and taste were at par for omega-3 rich energy bar samples having 10% flaxseed (Mridula *et al.*, 2011).

5 Conclusion

The purpose of this review was to summarize the incorporation of flaxseed to enrich different products such as baked, dairy, extruded and snacks. Along with that present review focuses on the impact of different amount of supplementation on nutritional, physicochemical and sensory properties of these products. Studies revealed that significant increase in nutritional value of value added products was observed in terms of ash, protein, dietary fiber and omega-3 fatty acid when enriched with flaxseed. With the incorporation of flaxseed in suitable concentration helped to improve physicochemical, textural, color, and sensory properties of different products. More research is needed to develop quick, reproducible and cost-effective practices for developing value added flax seed enriched products.

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