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Review Article

Flaxseed: A Rich Source of Bioactive Compounds with Potential Health Benefits

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Abstract:

Flaxseed (Linum usitatissimum L.) is a nutritional powerhouse rich in alpha-linolenic acid (omega-3 fatty acid), lignans (especially secoisolariciresinol diglucoside), and dietary fiber. These bioactive components possess anti-oxidant, anti-inflammatory, and lipid-modulating properties, suggesting potential health benefits for humans and animals. This review explores the effects of flaxseed consumption or its isolated bioactive ingredients on various health conditions. We delve into existing research on the potential impact of flaxseed on cardiovascular health, cancer, gut health, brain function, and hormonal balance in menopausal women. The review highlights the unique composition of flaxseed, including its high content of alpha-linolenic acid (over 70% of total oil), protein (20–30%), and dietary fibre (28%). Flaxseed also has the highest lignan concentration among plant sources. This distinct chemical profile positions flaxseed as a promising candidate for exploring its preventive and functional properties. The review emphasises the well-established safety of flaxseed under proper storage and processing conditions.

Key words: flaxseed; Linum usitatissimum L; alpha-linolenic acid; omega-3 fatty acids; lignans; secoisolariciresinol diglucoside; dietary fibre, cardiovascular health; cancer; gut health; brain function; menopause

1.Introduction

Flax (Linum usitatissimum), a member of the Lineaceae family, is an annual plant with delicate blue flowers that produces small, flat seeds ranging in colour from golden yellow to reddish brown (Dey & Przybylski, 1994). These seeds, commonly referred to as flaxseed or linseed (synonymous terms), boast a nutty flavour and a crunchy texture (Shahidi & Shewfelt, 2007). While flax has a multitude of uses, the seeds themselves are primarily utilised for human consumption (Dey & Przybylski, 1994). In contrast, the strong and durable fibres extracted from the flax stem are used for industrial purposes (Dey & Przybylski, 1994). Flaxseed consumption has a rich history, dating back to ancient times (Bedigian et al., 2018). Cultivated as a dietary supplement, fibre source, and medicinal herb, flaxseed has transcended geographical boundaries and is now grown in over 50 countries, predominantly in the Northern Hemisphere (Dey & Przybylski, 1994). Canada stands out as a major producer and exporter of flaxseeds (Dey & Przybylski, 1994). However, significant contributions also come from Ethiopia, China, India, and the United States (Dey & Przybylski, 1994). Interestingly, India holds the distinction of being the top producer in terms of acreage, accounting for 23.8% of the global total, while ranking third in production with a 10.2% contribution (Dey & Przybylski, 1994). Cultivation in India is primarily concentrated in Madhya Pradesh, Maharashtra, Chattisgarh, and Bihar (Dey & Przybylski, 1994).The discovery of flaxseed's Indian origins and its historical significance as a staple crop is a fascinating fact (Dey & Przybylski, 1994). Even today, flaxseed remains a versatile element in Indian cuisine, employed for both culinary and medicinal purposes (Dey & Przybylski, 1994). Its diverse applications contribute to its well-deserved reputation within the oilseed category (Dey & Przybylski, 1994). The growing popularity of flaxseed as a nutritional powerhouse can be attributed to its exceptionally high levels of dietary fibre, high-quality protein, phytoestrogens, and alpha-linolenic acid (ALA) (Dey & Przybylski, 1994; Bedigian et al., 2018). In fact, flaxseed boasts an impressive composition, with ALA accounting for approximately 55%, protein at 28–30%, and fibre content reaching 35% (Dey & Przybylski, 1994).

The unique blend of biologically active components in flaxseed, including lignan-secoisolariciresinol diglycoside (SDG), dietary fibre, and ALA, has captured the attention of both nutritionists and medical researchers due to their potential health benefits (Dey & Przybylski, 1994; Bedigian et al., 2018).

Nutrients	Amount per 100 g of edible flaxseed
Moisture (g)	6.5
Protein (N×6.25) (g)	20.3
Fat (g)	37.1
Minerals (g)	2.4
Crude fibre (g)	4.8
Total dietary fibre (g)	24.5
Carbohydrates (g)	28.9
Energy (kcal)	530.0
Potassium	750.0
Calcium (mg)	170.0
Phosphorous (mg)	370.0
Iron (mg)	2.7
Vitamin A (µg)	30.0
Vitamin E (mg)	0.6
Thiamine (B1) (mg)	0.23
Riboflavin (B2) (mg)	0.07
Niacin (mg)	1.0
Pyridoxine (mg)	0.61
Pantothenic acid	0.57
Biotin (µg)	0.6
Folic acid (µg)	112

Source: USDA National Nutrient Database for Standard Reference: https://fdc.nal.usda.gov/fdc-app.html#/food-details/169414/nutrients

Table 1: Nutritional composition of flaxseeds

1.1. The Dietary Use of Flaxseed: Balancing Benefits and Palatability

Flaxseed boasts a unique nutritional profile, rich in bioactive constituents like lignans, fibre, and alpha-linolenic acid (ALA) (Bedigian et al., 2018). Potential health benefits have linked these components to flaxseed, making it an attractive dietary addition. Consumable forms of flaxseed primarily include whole flaxseed, ground flaxseed, flaxseed oil, partially defatted flaxseed meal, and the recently introduced flax milk (Dey & Przybylski, 1994; Pizzey Ingredients Inc., n.d.).

Flax milk, a combination of finely ground flaxseed, filtered water, and other minor ingredients, offers a lactose- and cholesterol-free alternative to dairy milk (Pizzey Ingredients, Inc., n.d.). Its high ALA content and suitability for those with gluten, nut, or soy allergies make it an appealing option (Pizzey Ingredients Inc., n.d.).

However, widespread adoption of flaxseed hinges on its palatability. Despite potential health benefits, consumers often prioritise taste, texture, appearance, colour, and aroma (Dey & Przybylski, 1994). Unfortunately, flaxseed poses some challenges in these areas. Its bitterness and high omega-3 fatty acid content, which is susceptible to oxidation and rancidity, can have a negative impact on flavor (Dey & Przybylski, 1994). The oxidation process, triggered by high ALA concentrations, can lead to unpleasant musty smells and flavours (Dey & Przybylski, 1994).

Fortunately, flaxseed possesses a natural defence mechanism. Secoisolariciresinol diglucoside (SDG), an abundant antioxidant in flaxseed, helps prevent oxidation (Dey & Przybylski, 1994). Additionally, research suggests that flaxseed has a "nice nutty smell and aroma", which opens up opportunities for its incorporation into various dishes (Dey & Przybylski, 1994). Studies have demonstrated the successful integration of flaxseed into bread, buns, muffins, bagels, and snack bars (Dey & Przybylski, 1994).

The amount of flaxseed included in a food item significantly influences its flavour profile. Studies have explored incorporating flaxseed at

concentrations ranging from 5% to 28% of the total weight in baked goods (Dey & Przybylski, 1994). Research also suggests daily consumption of up to 40–50 grammes of flaxseed is safe, with clinical trials demonstrating successful year-long daily intake by patients (Dey & Przybylski, 1994). However, these studies also highlight a crucial point: long-term adherence requires variety. Introducing flaxseed into a wider range of foods can prevent monotony and improve compliance compared to consuming pure flaxseed (Dey & Przybylski, 1994).

Baked goods provide a natural canvas for incorporating flaxseed. Studies show that baking muffins with flaxseed for two hours at 178°C (352°F) does not alter ALA content (Dey & Przybylski, 1994). Furthermore, baking allows for the for of any undesirable flavours associated with bitterness or slight rancidity through the addition of various flavourings (Dey & Przybylski, 1994). Research has explored flavours like cranberry orange, cappuccino chocolate chip, and cinnamon raisin, offering options to cater to diverse preferences (Dey & Przybylski, 1994). A year-long study investigating daily preferences for flaxseed-containing food products (30 g of ground flaxseed) revealed a clear preference for bagels over muffins, snack bars, and other options (Dey & Przybylski, 1994). Similarly, cinnamon and raisin flavours were favoured over alternatives like cranberries and oranges (Dey & Przybylski, 1994). Flax milk's recent emergence presents an even more convenient approach to consuming and potentially preserving flaxseed's benefits.

1.2 Antioxidant Properties of Flaxseed: Combating Free Radicals and Beyond.

Flaxseed's potential health benefits stem in part from its impressive antioxidant properties. Studies suggest that these properties contribute to lowering total cholesterol and reducing platelet aggregation (Simons et

al., 1998). Researchers have identified flaxseed lignans, particularly secoisolariciresinol diglucoside (SDG), and the mammalian lignans enterodiol (ED) and enterolactone (EL), as potent antioxidants (Chen et al., 2006). Their mechanism of action involves protecting against lipid peroxidation and DNA damage, effectively combating free radicals within the body (Chen et al., 2006).

Research has gone beyond identifying these lignans. Studies have investigated the specific components responsible for the antioxidant effects. Researchers looked at high doses of ED, EL, and Secoisolariciresinol (SECO) and found that the 3-methoxy-4-hydroxyl parts on SDG and SECO are very important for their antioxidant activity (Chen et al., 2006).

Interestingly, flaxseed's SDG may also play a role in preventing or delaying the onset of type 1 and type 2 diabetes (Chen et al., 2011). The proposed mechanism attributes this effect to SDG's antioxidant activity and its potential impact on blood sugar control in individuals with type 2 diabetes (Chen et al., 2011). In particular, SDG may help lower blood sugar by blocking the phosphoenolpyruvate carboxykinase enzyme, which is a rate-limiting enzyme in the gluconeogenesis pathway (Chen et al., 2011).

1.3 Anti-Inflammatory Properties of Flaxseed: Taming the Fire Within

Flaxseed and flaxseed oil are significant dietary sources of antioxidants due to the presence of lignans, phenolic acids, and tocopherols (Zhang et al., 2009). Research suggests that flaxseed consumption can contribute to reducing inflammatory markers (Mirfatahi et al., 2008). In hemodialysis patients, Mirfatahi et al. (2008) investigated the impact of flaxseed oil consumption on serum systemic and vascular inflammatory markers. The study randomly assigned participants to either the flaxseed oil group or the control group. For eight weeks, the flaxseed oil group consumed 6 grammes of flaxseed oil daily, while the control group received 6 grammes of medium-chain fatty acids. We collected blood samples at baseline and after eight weeks to measure levels of various inflammatory markers. Researchers found that the flaxseed oil group had much lower levels of sVCAM-1 and hs-CRP than the control group and the levels that were already there (Mirfatahi et al., 2008). These findings suggest that flaxseed oil may be beneficial in reducing specific inflammatory markers.

1.4 Flaxseed and Menopausal Symptoms: A Promising Potential Ally

Flaxseed consumption has emerged as a potential dietary approach for alleviating menopausal symptoms. A study by Boucher et al. (2006) investigated the impact of flaxseed on menopausal symptoms in 90 women (Boucher et al., 2006). Boucher et al. (2006) randomly divided the participants into three groups: one group received a daily dose of 1 g of flaxseed extract containing at least 100 mg of SDG, another group received 90 g of ground flaxseed (providing at least 270 mg of SDG daily), and a control group received 1 g of collagen daily. Before and after a six-month intervention, Boucher et al. (2006) assessed the Kupperman index, a measure of endometrial thickness, vaginal cytology, and menopausal symptom severity. The findings revealed a significant reduction in the intensity of menopausal symptoms in both the flaxseed extract and ground flaxseed groups compared to the control group (Boucher et al., 2006). The Kupperman index and hot flush frequency decreased in tandem with these reductions (Boucher et al., 2006). Importantly, Boucher et al. (2006) observed no significant changes in endometrial or vaginal epithelium in any group. These findings suggest that flaxseed, in either extract or ground form, may offer benefits in managing menopausal symptoms.

Further evidence supporting the potential role of flaxseed in menopause comes from a study by Cederroth et al. (2007) (Cederroth et al., 2007). This study involved 140 women, divided into four groups (Cederroth et al., 2007). One group received 5 g of flaxseed daily without hormone replacement therapy (HRT), another received 5 g of flaxseed daily with HRT, a third group received HRT alone, and a fourth group served as the control (Cederroth et al., 2007). Participants completed assessments of menopausal symptoms and quality of life before and after the trial (Cederroth et al., 2007). The results demonstrated that women consuming flaxseed reported significantly lower menopausal symptom severity and a higher quality of life compared to those who did not consume flaxseed (Cederroth et al., 2007). These studies collectively suggest that flaxseed consumption may be a promising strategy for mitigating menopausal symptoms.

1.5 Flaxseed and Digestive Health: Aiding Your Gut

Flaxseed's soluble fibre content positions it as a potential prebiotic, fostering a healthy gut microbiota (Markie et al., 2017). A study by Brahe et al. (2015) explored the effects of dietary interventions on gut microbiota and metabolic risk markers in obese individuals (Brahe et al., 2015). Brahe et al. (2015) assigned participants to consume either Lactobacillus paracasei F19 or 10 grammes of flaxseed mucilage for six weeks. The results indicated that flaxseed mucilage consumption led to a decrease in insulin release and serum C-peptide levels, along with an increase in insulin sensitivity (Brahe et al., 2015). Furthermore, the study revealed changes in the abundance of 33 gut microbiota species following flaxseed mucilage intervention (Brahe et al., 2015). These findings suggest that flaxseed may contribute to a healthier gut environment.

Flaxseed oil, on the other hand, demonstrates promise in alleviating constipation (Khoshbaten et al., 2012). A study by Khoshbaten et al. (2012) investigated the impact of daily flaxseed oil consumption (6.9 ± 2.7 mL) on constipation in constipated adults for four weeks (Khoshbaten et al., 2012). The results demonstrated a significant improvement in the Rome III score, a scoring system used to assess constipation severity (Khoshbaten et al., 2012). The primary effects observed were increased evacuation frequency and improved stool consistency (Khoshbaten et al., 2012). These findings suggest that flaxseed oil may be a beneficial dietary supplement for managing constipation.Flaxseed ingestion may also contribute to weight management by increasing faecal fat excretion (Kristensen et al., 2009). A study by Kristensen et al. (2009) investigated the effects of consuming 5 grammes of viscous dietary fibre from flaxseeds daily for one week on faecal fat excretion in healthy individuals The results showed a significant increase in faecal fat excretion compared to a control group (Kristensen et al., 2009).Flaxseed consumption may also reduce endotoxemia and intestinal permeability (van der Sanden-Besseling et al., 2014). However, further research is necessary to fully comprehend these potential effects.

1.6 Flaxseed and the Nervous System

Flaxseed consumption may benefit the neurological system and cause mental fatigue. Gholami et al. (2014) investigated the impact of flaxseed on physical and mental fatigue in overweight children and adolescents (Gholami et al., 2014). Gholami et al. (2014) randomised participants into two groups with a body mass index (BMI) greater than 25 kg/m2. For four weeks, one group consumed 20 grammes of flaxseed daily, while the other group received 25 grammes of puffed wheat (Gholami et al., 2014). Gholami et al. (2014) assessed height, waist circumference, body weight, mood (anxiety, stress, depression), hunger, and fatigue. The group consuming flaxseed exhibited a significant decrease in mental fatigue compared to the puffed wheat group (Gholami et al., 2014). However, regular flaxseed consumption did not affect anxiety, depression, overall fatigue, motivation, or activity levels (Gholami et al., 2014).

Flaxseed oil supplementation may also influence psychological well-being and brain-derived neurotrophic factor (BDNF) levels in women with depression (Mazza et al., 2017). Mazza et al., 2017 randomly assigned participants to two groups and administered either 1000 mg of flaxseed oil twice daily or a placebo for ten weeks. We obtained anthropometric measures and serum BDNF levels before and after the intervention (Mazza et al., 2017). We assessed the severity of depression symptoms using the Beck Depression Inventory-II (BDI-II) questionnaire

(Mazza et al., 2017). The group that took flaxseed oil supplements had a significantly lower total BDI-II score (-16.62 ± 7.03 vs. -8.45 ± 7.8; $p < 0.001$) and significantly higher serum BDNF levels (1.12 ± 0.6 pg/mL vs. 0.2 ± 0.56 pg/mL; $p < 0.001$) compared to the placebo group (Mazza et al., 2017). These findings suggest that flaxseed oil supplementation may improve depressive symptoms.

1.7 Flaxseed and the Skin: An Energetic Friend?

Flaxseed oil's omega-3 fatty acids hold promise for enhancing skin health (Neukam et al., 2008). A study by Neukam et al. (2008) investigated the effects of flaxseed oil supplementation on skin health (Neukam et al., 2008). Neukam et al. (2008) divided the participants into two groups and administered either four capsules containing 555.32 mg of flaxseed oil or four capsules containing 560 mg of safflower oil daily for twelve weeks. Neukam et al. (2008) assessed skin moisture, sensitivity, transepidermal water loss, and plasma polyunsaturated fatty acids at baseline, week 6, and week 12. The group that received flaxseed oil supplements demonstrated significantly higher levels of epidermal hydration and smoothness in comparison to the safflower oil group. They also had less transepidermal water loss, skin roughness, scaling, and sensitivity. These findings suggest that flaxseed oil supplementation may contribute to improved skin health.

Omega-3 fatty acids from flaxseed may also accelerate wound healing (Zayeh et al., 2014). A study by Zayeh et al. (2014) looked at how fast diabetic foot ulcers healed in people who took either 1000 mg of omega-3 fatty acids from flaxseed oil supplements twice a day or a placebo for 12 weeks (Zayeh et al., 2014). The group receiving flaxseed oil supplements experienced a significant reduction in ulcer length and depth compared to the control group (Zayeh et al., 2014). Although further research is necessary to validate these findings, flaxseed oil exhibits potential in fostering wound healing.

1.8 Cancer and Flaxseed: Promising Leads, Needing More Evidence

Flaxseed's potential role in cancer prevention and management is a topic of ongoing research. A pilot study by Azhar Jabeen et al. (2014) explored the effects of dietary fat restriction and flaxseed supplementation in men with prostate cancer (Azhar Jabeen et al., 2014). The participants consumed 30 grammes of ground flaxseed daily while following a low-fat diet, providing no more than 20% of total calories from fat over the 34-day study period (Azhar Jabeen et al., 2014). The study observed significant reductions in total testosterone, total cholesterol, and free androgen index (Azhar Jabeen et al., 2014). Additionally, Azhar Jabeen et al., 2014 observed a decrease in the mean proliferation rate and a shift in the distribution of apoptotic indexes. These findings, while promising, require further investigation in larger and longer-term clinical trials.

Animal studies have shown that flaxseed may lower the incidence and early risk markers of colon and breast cancer (Serraino & Thompson, 1991; Thompson et al., 1996). Epidemiological studies have also indicated a correlation between vegetarian diets and lower breast cancer rates in certain populations (Block et al., 1992; Parkin et al., 1992). Furthermore, studies have observed lower levels of lignans in omnivores and breast cancer patients (Adlercreutz et al., 1982; Adlercreutz et al., 1993). These findings suggest that flaxseed's lignan content may hold promise for cancer prevention. A comprehensive review by Flower et al. (2013) examined the effects of lignans and other flaxseed components on menopausal symptoms in breast cancer patients, as well as their potential impact on breast cancer incidence or recurrence (Flower et al., 2013). Based on their analysis of existing research, Flower et al. (2013) concluded that flaxseed may lower the risk of breast cancer and exhibit anti-proliferative properties in breast tissue from women at risk of breast cancer. However, more research is required to confirm these findings.

2.Future Research Directions: Unveiling the Full Potential of Flaxseed

While the potential health benefits of flaxseed are intriguing, further research is necessary to solidify its place as a reliable herbal product. Here, we delve into key areas that future research should explore:

2.1 Bolstering the Evidence Base: The Need for Robust Clinical Studies

A significant portion of the current research on flaxseed comes from observational studies or small clinical trials (Thomson, 2016). Large-scale, well-designed randomised controlled trials (RCTs) are necessary to definitively establish the effectiveness of flaxseed for various health conditions (Thomson, 2016). These studies would involve dividing participants into groups, with one group receiving flaxseed and the other receiving a placebo, while controlling for other factors that might influence health outcomes. By rigorously evaluating the results of such studies, researchers can build a stronger foundation for understanding the true impact of flaxseed consumption (Thomson, 2016).

2.2 Dosage, Processing, and Individual Variability: A Tailored Approach

Unknown factors may influence the effectiveness of flaxseed. Future research should investigate the optimal dosage of flaxseed for specific health benefits. Does a daily tablespoon provide the same results as a daily teaspoon? Furthermore, processing methods such as grinding or consuming whole flaxseeds have the potential to influence nutrient absorption and health effects (Thielecke & Christianson, 2016). Furthermore, individual variations in gut microbiome composition and genetics may influence how people respond to flaxseed consumption (Gibbons et al., 2015). Research that considers these factors can help develop personalised recommendations for incorporating flaxseed into one's dietary regimen (Thielecke & Christianson, 2016).

2.3 Long-Term Effects and Specific Conditions: Unveiling Flaxseed's Full Spectrum

Much of the current research focuses on short-term outcomes. Future studies should explore the long-term effects of flaxseed supplementation on various health markers. Can regular flaxseed consumption contribute to a lower risk of chronic diseases like heart disease or certain cancers over time? Additionally, investigating the impact of flaxseed on specific health conditions, such as diabetes, hormonal imbalances, or inflammatory bowel disease, could provide valuable insights for targeted therapeutic applications (Wang et al., 2013; Lagiou et al., 2006; Bawadi et al., 2014).

2.4 Exploring Synergistic Effects and Mechanisms of Action

Flaxseed is a complex blend of various nutrients. Future research should delve deeper into the potential synergistic effects of these components and how they work within the body to produce health benefits (Syvänne et al., 2009). Understanding the mechanisms of action—the biological pathways through which flaxseed exerts its effects—will be crucial for developing targeted interventions and maximising its therapeutic potential (Syvänne et al., 2009).By addressing these future research directions, we can move beyond the realm of promising possibilities and establish flaxseed as a reliable and evidence-based tool for promoting health and well-being. This comprehensive understanding will empower individuals and healthcare professionals to make informed decisions about incorporating flaxseed into dietary and therapeutic strategies.

3. Conclusion:

Flaxseed, a versatile herbal product with a rich history, has captured the interest of modern consumers seeking natural ways to enhance their health. Researchers have linked its unique composition, rich in omega-3 fatty acids, lignans, and fibre, to a variety of potential health benefits, including improved cardiovascular health, improved digestive function, and even a reduced risk of certain cancers. Traditional uses highlight its historical applications for various ailments, demonstrating its long-

standing association with well-being. However, it's crucial to acknowledge that the scientific evidence for many of these benefits is still emerging. While the potential is promising, further research through well-designed clinical studies is necessary to solidify flaxseed's place as a reliable therapeutic tool. Additionally, responsible use is key. Consulting with a healthcare professional before incorporating flaxseed into one's diet is essential, especially for individuals with existing health conditions or those taking medications. Despite these considerations, the future of flaxseed research is bright. Exploring the role of dosage, processing methods, and individual variations holds immense promise for a more personalised approach to harnessing its potential. Furthermore, studying long-term effects and their impact on specific health conditions could pave the way for targeted therapeutic applications. Unveiling the synergistic effects of flaxseed's various components and understanding its mechanisms of action will be crucial for maximising its health benefits. In conclusion, flaxseed offers a seed of promise in the world of herbal products. By acknowledging its potential while embracing the need for further research and responsible use, we can unlock its true potential for promoting overall health and well-being in the years to come.

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