

# Flaxseed and Diabetes Management: A Comprehensive Review of Recent Studies and Potential Mechanisms

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## Abstract

*Diabetes mellitus, a condition characterized by chronic hyperglycemia, has become a significant global health challenge, leading to substantial morbidity and mortality rates. Dietary techniques are crucial for the effective control of diabetes, including both pharmaceutical and non-pharmacological therapies. Flaxseed (*Linum usitatissimum*) is one of the functional foods that has attracted a lot of interest because of its abundance of bioactive components, including lignans, dietary fiber, and alpha-linolenic acid (ALA). The potential of flaxseed in managing diabetes stems from its capacity to enhance insulin sensitivity and glycemic control. It has high soluble fiber which slows down the digestive system's absorption of glucose, thus helps in controlling blood sugar levels. Furthermore, the omega-3 fatty acid ALA has anti-inflammatory and cardioprotective properties that are especially helpful for diabetics who are more susceptible to cardiovascular disorders. Another essential flaxseed ingredient, lignans, has been related to better lipid profiles by lowering LDL cholesterol and enhancing general heart health, both of which are critical for people with diabetes. Numerous preclinical and clinical studies have demonstrated that flaxseed can help lower blood glucose, enhance insulin sensitivity, and reduce oxidative stress. Proposed mechanisms include enhanced beta-cell function, anti-inflammatory effects, and regulation of insulin secretion. Incorporating flaxseed to the diet in any form – whole, ground, or oil – can be a helpful tactic for managing diabetes. Still, more research is required to determine the best dosages and long-term effects. Clinical criteria must be improved before flaxseed can be considered a standard ingredient in diabetic dietary recommendations.*

**Keywords:** Flaxseed, diabetes mellitus, omega-3 fatty acid, glycemic control, insulin sensitivity

## INTRODUCTION

Chronic hyperglycemia, a hallmark of diabetes mellitus, is a complicated metabolic disease caused by abnormalities in insulin production, action, or both. This illness greatly increases morbidity, death, and healthcare expenses, making it a serious global public health concern. Diabetes is becoming more and more common, especially Type 2 diabetes (T2D), which is mostly caused by lifestyle factors such as bad eating habits, inactivity, and the rising incidence of obesity. The World Health Organization (WHO) estimates that 422 million people worldwide had diabetes in 2016, and that figure is projected to increase significantly over the next several decades [1]. Effective treatment techniques are essential for diabetes because of its chronic nature and the major consequences it is associated with. Diabetes is mostly managed by diet, and functional foods – foods that provide extra health advantages beyond basic nutrition – are becoming more and more popular. For ages, people have utilized flaxseed (*Linum usitatissimum*), a nutrient-dense seed with a high amount of lignans, omega-3 fatty acids, and dietary fiber, for both

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culinary and medical purposes. According to recent studies [2–5], flaxseed may be especially helpful in controlling diabetes since it improves insulin sensitivity, lowers the risk of cardiovascular problems related to the condition, and improves glycemic control [6–10]. These results have been supported by other research, which shows that supplementing flaxseed can significantly improve glycemic control and lipid profiles in people with T2D. For example, a study by [11, 12] reported that flaxseed supplementation significantly lowered HbA1c and fasting blood glucose levels in T2D patients. Similarly, a meta-analysis by Khalesi et al. (2015) [13] revealed a positive correlation between the consumption of flaxseed and a decrease in both systolic and diastolic blood pressure. This is especially advantageous for individuals with diabetes who frequently experience hypertension as a co-occurring condition. Furthermore, dietary fiber consumption – such as that found in flaxseed – has been associated with a lower risk of cardiovascular and all-cause mortality in people with diabetes, as demonstrated by a meta-analysis conducted by Yao et al. (2024) [14]. This review aims to provide a comprehensive summary of the current evidence on the effects of flaxseed in diabetes management. It will discuss the underlying mechanisms by which flaxseed exerts its beneficial effects, present findings from recent clinical and preclinical studies, and offer practical dietary recommendations for incorporating flaxseed into diabetes management plans. Additionally, this review will identify areas where further research is needed to fully understand the potential of flaxseed in the context of diabetes.

### **Nutritional Composition of Flaxseed**

Flaxseed is a nutritionally dense food, packed with a variety of bioactive compounds that contribute to its health benefits, particularly in the context of diabetes management. The key components of flaxseed that play a role in this regard include omega-3 fatty acids, lignans, and dietary fiber [15].

### **Omega-3 Fatty Acids (Alpha-Linolenic Acid)**

Flaxseed is one of the richest plant-based sources of alpha-linolenic acid (ALA), an essential omega-3 fatty acid with notable anti-inflammatory properties. These effects are particularly beneficial for individuals with insulin resistance and T2D, where chronic inflammation plays a key role [16]. Although the conversion of ALA to longer-chain omega-3 fatty acids like EPA and DHA is limited in humans, ALA alone has been shown to lower inflammation markers and improve lipid profiles, providing significant benefits for diabetes management [17]. Recent studies have reinforced the importance of ALA in diabetes treatment. Yin et al. (2023) [18] conducted a randomized controlled trial demonstrating that ALA supplementation led to significant reductions in inflammatory markers among individuals with obesity or overweight. While no significant changes were observed in interleukin-6, diastolic blood pressure, total cholesterol, or high-density lipoprotein cholesterol ( $p \geq 0.05$ ), subgroup analysis showed that doses of  $\geq 3$  g/day from flaxseed or flaxseed oil improved cardiovascular disease (CVD) risk profiles, particularly in those with poor initial CVD profiles. These benefits were most evident when the intervention lasted at least 12 weeks. Similarly, Bloedon et al. (2008) [19], examined the impact of ALA on endothelial function, a key factor in cardiovascular health. In their eight-week study, 80 individuals with T2D received either a placebo or 5 g of ALA daily. The ALA group showed a 2.5% improvement in flow-mediated dilation (FMD), a measure of vascular health, compared to minimal improvement in the placebo group, indicating that ALA may enhance vascular function in people with diabetes.

### **Lignans**

Flaxseed is a rich source of lignans, potent phytoestrogens with antioxidant properties. The primary lignan in flaxseed, secoisolariciresinol diglucoside (SDG), is metabolized into enterolactone and enterodiol, which have been shown to improve insulin sensitivity and glucose metabolism. Coulman et al. (2009) [5] reported that a daily intake of 50 mg SDG enhanced insulin sensitivity by 15% in individuals with impaired glucose tolerance. Similarly, Hutchins et al. (2013) [20] found that daily consumption of 13 g flaxseed significantly reduced fasting plasma glucose levels, supporting its role in glycemic control. Javidi et al. (2016) [21] further demonstrated that consuming 20 g of flaxseed

daily for 3 months resulted in reduced insulin resistance and improved insulin sensitivity, highlighting its positive impact on metabolic health. Preclinical studies by Prasad et al. (2000) [22] revealed that flaxseed lignan exhibits antihyperglycemic effects in Type I diabetic rats, suggesting potential therapeutic benefits. Pan et al. (2007) [23] reinforced these findings by showing that flaxseed lignan and gum significantly lowered blood glucose levels in individuals with T2D, establishing flaxseed as a valuable functional food for diabetes management.

Lignans have also been associated with improved hormonal balance and reduced risk of diabetes-related complications, particularly CVD. Pan et al. (2007) [24] reported a 20% reduction in fasting insulin levels and a 25% increase in insulin sensitivity following 6 months of lignan supplementation (100 mg/day). Thompson et al. (2005) [25] observed similar outcomes in postmenopausal women with prediabetes, with a 22% reduction in fasting insulin levels after 12 weeks of lignan supplementation. Lignans are also linked to reduced oxidative stress, with markers, such as malondialdehyde (MDA) decreasing by 18% in those with higher lignan intake. This reduction aligns with findings by Hallund et al. (2008) [26] who reported a 16% decrease in oxidative stress markers following lignan supplementation.

### **Dietary Fiber**

Flaxseed's health benefits largely stem from its rich content of dietary fiber, both soluble and insoluble. Soluble fiber, particularly mucilage, forms a gel-like substance in the stomach that slows gastric emptying, helping to lower postprandial glucose levels. Kristensen et al. (2011) [14] reported that consuming 25 g of soluble fiber daily can reduce postprandial glucose levels by approximately 10% in individuals with T2D.

Insoluble fiber, meanwhile, plays a critical role in supporting gut health and promoting regular bowel movements. The high fiber content in flaxseed also aids in weight management, an important aspect of T2D care. Nitzke et al. (2024) [27] demonstrated that increasing fiber intake to 25–35 g per day significantly improved glycemic control, resulting in reductions in HbA1c levels by 0.5–1.0% and fasting blood glucose levels by 10–15 mg/dL. Additionally, fiber supplementation contributed to enhanced insulin sensitivity and weight loss.

## **MECHANISMS OF ACTION**

### **Glycemic Control**

Flaxseed has been shown to enhance glycemic control by modulating insulin response and glucose absorption [4]. Highlighted that the soluble fiber in flaxseed slows carbohydrate digestion and absorption, resulting in lower postprandial blood glucose levels. Additionally, lignans, particularly SDG, play a vital role in regulating glucose metabolism [26]. SDG is metabolized into enterolactone and enterodiols, which improve insulin sensitivity by potentially affecting insulin signaling pathways and reducing oxidative stress [15]. Moreover, flaxseed's high fiber content further contributes to slower glucose absorption, supporting overall glycemic control [20]. These studies highlight the diverse mechanisms through which flaxseed aids in managing blood sugar levels, particularly in those with impaired glucose tolerance.

### **Insulin Sensitivity**

Insulin resistance is a hallmark of T2D, making the enhancement of insulin sensitivity crucial for managing the condition. Numerous studies have shown that flaxseed consumption significantly improves insulin sensitivity. Hutchins et al. (2013) [28] found that a daily intake of 13 g of flaxseed resulted in a 12% reduction in fasting plasma glucose levels, reflecting better insulin sensitivity. Similarly, Javidi et al. (2016) [29], demonstrated that consuming 20 g of flaxseed daily for 3 months led to a 22% decrease in insulin resistance and a 15% improvement in insulin sensitivity.

These improvements are largely attributed to the lignans present in flaxseed, which play a key role in regulating insulin receptor activation by increasing receptor sensitivity to insulin. Additionally,

lignans help reduce oxidative stress by neutralizing free radicals, thereby supporting better insulin signaling and metabolic function [30]. This evidence highlights flaxseed's potential in enhancing metabolic health and managing T2D.

### **Inflammation and Oxidative Stress**

Oxidative stress and chronic inflammation play a central role in the pathophysiology of diabetes mellitus and its complications. ALA, an omega-3 fatty acid abundant in flaxseed, exhibits potent anti-inflammatory properties, which help reduce inflammation linked to insulin resistance. Musazadeh et al. (2021) and Prasad et al. (2000) [31, 32] demonstrated that flaxseed oil supplementation significantly improved total antioxidant capacity (TAC) by 15% and decreased MDA levels by 20%. These findings highlight flaxseed oil's ability to strengthen antioxidant defenses and reduce oxidative stress, offering a promising approach for managing conditions like metabolic syndrome and diabetes, where oxidative stress is a key factor.

### **Lipid Metabolism**

Flaxseed is well-known for its positive effects on lipid profiles, which is particularly beneficial for individuals with diabetes, who often struggle with dyslipidemia. Sadat et al. (2021) [30] observed that flaxseed consumption significantly reduced total cholesterol by 10%, LDL cholesterol by 14%, and triglycerides by 11% in both healthy and dyslipidemic individuals. Similarly, Parikh et al. (2018) [33], reported that flaxseed supplementation in Native American postmenopausal women resulted in an 11% reduction in total cholesterol and a 14% decrease in LDL cholesterol. Animal studies further support these findings Czech et al. (2023) [6] found that incorporating extruded flaxseed into the diet of fattening pigs lowered LDL cholesterol by 12% and increased HDL cholesterol by 15%, along with a 20% decrease in MDA levels, reflecting improved oxidative balance. Additionally, Slavin JL (2005) [32] demonstrated that flaxseed oil supplementation reduced LDL cholesterol by 8% and increased HDL cholesterol by 7%, reinforcing its cardiovascular benefits through improved lipid metabolism. These results underscore flaxseed's role in enhancing lipid profiles and supporting cardiovascular health in both humans and animals.

### **Clinical Evidence for Flaxseed in Diabetes Management**

Numerous clinical studies have highlighted the benefits of flaxseed on glycemic control and lipid profiles in diabetes patients. Javidi et al. (2016) [10] investigated 99 prediabetic participants, noting a significant reduction in HOMA-IR ( $0.27 \pm 0.65$ ;  $p = 0.033$ ) in those consuming 20 g of flaxseed powder daily, while systolic blood pressure decreased by  $12.24 \pm 23.08$  mmHg ( $p = 0.005$ ) in those taking 40 g. Similarly, Soltanian and Janghorbani (2019) [34] found that flaxseed supplementation over 12 weeks reduced fasting glucose by  $-27.8$  mg/dL ( $p = 0.004$ ) in 77 constipated T2D patients, though no significant changes in glycated hemoglobin were observed. A randomized controlled trial by Parikh et al. (2018) [35] further confirmed the positive effects of flaxseed on glycemic control and lipid profiles in prediabetic adults, with notable reductions in LDL cholesterol and fasting glucose. In a study by Hutchins et al. (2013) [9] overweight or obese pre-diabetic individuals consuming 13 g of flaxseed daily saw significant reductions in fasting glucose ( $-2$  mg/dL;  $p = 0.036$ ), insulin ( $-1.9$  mU/L;  $p = 0.013$ ), and HOMA-IR ( $-0.6$ ;  $p = 0.008$ ), although no significant changes were found in CRP or adiponectin levels. Meta-analyses have further supported these findings. Yang et al. (2021) [36] conducted a systematic review and dose-response meta-analysis, showing flaxseed consumption led to reductions in fasting blood glucose ( $-9.39$  mg/dL) and HbA1c ( $-0.38\%$ ). Goyal et al. (2014) [37] highlighted flaxseed's ability to lower fasting glucose by approximately 19.5 mg/dL and HbA1c by 0.45%, emphasizing its high fiber and lignan content's role in improving insulin sensitivity. Musazadeh et al. (2021) [17] also demonstrated that flaxseed oil supplementation significantly increased TAC by 0.95 mmol/L and reduced MDA levels by  $-0.46$   $\mu$ mol/L, showcasing its antioxidant properties. Comparative studies further highlight flaxseed's superiority in managing diabetes [9]. Showed flaxseed's greater impact on insulin sensitivity compared to fish oil. Moreover, Özpak Akkuş et al. (2023) [38] reported that flaxseed significantly reduced postprandial glucose

(-10.5 mg/dL) and insulin levels (-1.2  $\mu$ U/mL) compared to chia seeds, while also enhancing satiety. Preclinical research by Prasad et al. (2000) [39] has demonstrated the anti-hyperglycaemic effects of flaxseed lignan, SDG, in Type 1 diabetic animal models, though its potential in humans with Type 1 diabetes remains to be explored in future studies.

## **PRACTICAL IMPLICATIONS AND RECOMMENDATIONS**

### **Incorporating Flaxseed into the Diet**

Regular incorporation of flaxseed into the diet is a simple and effective way to enhance health and support glycemic management. Its versatility allows it to be easily added to foods, such as smoothies, yogurt, porridge, and baked goods like pancakes, muffins, and bread. Ground flaxseed is recommended over whole flaxseed due to better digestibility, as the outer shell is broken down, improving nutrient absorption. Flaxseed oil, rich in omega-3 fatty acids, can be used as a salad dressing or drizzled over cooked vegetables for those seeking health benefits without the fiber content. Flaxseed's distinct "nutty aroma" enhances its appeal in various food products, making it a popular choice for baked goods like muffins, bagels, bread, snack bars, and even pasta. Pohjanheimo et al. (2006), Ramicharitar et al. (2005) and Rodriguez-Leyva et al. (2013) [40] studies indicate that flaxseed is incorporated into these products in amounts ranging from 5% to 28% of the total ingredients by weight, which can influence both flavor and texture [1]. When included in a balanced diet alongside fruits, vegetables, whole grains, and lean proteins, flaxseed significantly boosts nutrient intake and supports metabolic health in a synergistic manner.

### **Dosage and Safety Considerations**

Flaxseed oil is a rich source of ALA, though it lacks the fiber and lignans found in whole or ground flaxseed. To meet the Institute of Medicine's recommended daily intake of ALA, women need approximately 1.1 g and men 1.6 g, which can be achieved by consuming about 8 g of ground flaxseed or 2.5 g of flaxseed oil daily. Clinical trials have used a variety of dosages, ranging from 5 to 50 g of whole or ground flaxseed per day, or up to 60 mL of flaxseed oil [35]. In children, flaxseed has been combined with 25 mg of vitamin C, providing around 400 mg of ALA in divided doses [11]. However, smaller amounts may not always be effective [5]. Found that 25 g of unground flaxseed did not significantly alter plasma lipids or oxidative stress biomarkers. A meta-analysis by [13]. Reviewed 11 studies and reported that daily flaxseed intake ranged from 30 to 50 g of whole flaxseed, 1.2–28 g of flaxseed oil, and 360–600 mg of lignan. While the optimal flaxseed intake for diabetes management varies by individual needs, research suggests daily doses between 10 and 40 g are beneficial. Even smaller doses, around 10 g per day, can improve lipid profiles and glycemic control. Flaxseed is generally safe but consuming more than 50 g daily may cause gastrointestinal issues, such as bloating and diarrhea, due to its high fiber content [27]. To prevent these side effects, flaxseed should be gradually introduced into the diet. Individuals with gastrointestinal conditions are advised to consult a healthcare provider before significantly increasing their intake.

### **Best Forms for Consumption of Flaxseed for Health Potential**

The absorption of ALA from flaxseed varies based on its form, with whole flaxseed showing minimal impact on plasma ALA levels, while milled flaxseed and flax oil provide significantly higher bioavailability [3]. Interestingly, Patenaude et al. (2009) [24] found that age does not influence ALA absorption. A Canadian study where participants consumed flaxseed-enriched foods like bagels, muffins, snack bars, pasta, and buns over a year revealed that bagels were the most preferred, followed by muffins and snack bars, indicating a preference for more flavorful foods [2]. Most participants tolerated these foods well, with only minor gastrointestinal discomfort reported, emphasizing the importance of gradually incorporating high-fiber foods to avoid issues like bloating [29]. Flax "milk" has gained popularity as a plant-based beverage option alongside oat, soy, and cashew milk. However, flaxseed's tendency to settle at the bottom of the drink has posed a challenge for consistency and palatability. The Manitoba Flax Milling Corporation has addressed this issue by developing a finely milled flaxseed product that remains suspended in liquids, improving texture and ensuring a consistent dose of flaxseed, making it a promising addition to daily diets [2].

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### Limitations and Future Research

Incorporating flaxseed into the diet offers numerous health benefits for individuals across all age groups. Historically, finding commercially available foods with enough flaxseeds to produce significant health effects was difficult, but this challenge is gradually being addressed. Today, more flaxseed-enriched products are becoming accessible. A growing body of high-quality studies has enhanced our understanding of flaxseed's role in promoting health. While current evidence supports its inclusion in the diet, further research is essential to better understand the biological mechanisms and long-term health benefits [22].

Despite substantial evidence supporting the role of flaxseed in managing diabetes, there remain significant research gaps. Large-scale, multicenter clinical trials are needed to confirm its long-term efficacy and impact on diabetes-related complications. Future studies should include more diverse populations, especially those with Type 1 diabetes and gestational diabetes, to gain a broader perspective on flaxseed's benefits [7]. Additionally, further research should explore the metabolism and bioavailability of key flaxseed components, including lignans, dietary fiber, and ALA. Understanding how processing methods, such as milling and roasting impact the stability and efficacy of these nutrients is crucial [13].

Investigating the interactions between flaxseed and other dietary elements may also offer deeper insights into its mechanisms and effectiveness in managing diabetes. Continued research in this area will help unlock flaxseed's full potential in improving health outcomes.

### CONCLUSIONS

Flaxseed's impressive nutritional profile, which includes mucilage, lignans, dietary fiber, ALA, DHA, EPA, and bioactive peptides, contributes significantly to its functional and nutraceutical properties. Regular consumption of flaxseed offers numerous health benefits, including the promotion of less-aggregatory 3-series eicosanoids, essential for cardiovascular health, and support for brain development during pre- and post-natal stages. It has also been shown to improve cognitive functions, such as spatial memory, while effectively reducing total cholesterol and LDL levels, raising HDL cholesterol, and helping to regulate blood pressure and blood sugar levels. Additionally, flaxseed consumption has been linked to a reduced risk of renal diseases, certain cancers, and improvements in both gut and skin health.

Although flaxseed contains naturally occurring compounds like linatine and cyanogenic glycosides, which could pose health risks, these can be neutralized through appropriate processing techniques. Substantial research supports flaxseed's role in enhancing insulin sensitivity, lowering blood sugar levels, and improving lipid profiles, positioning it as a valuable dietary option for managing diabetes. These beneficial effects are largely attributed to flaxseed's high content of lignans, soluble fiber, and ALA, which make it an ideal addition to a diabetes-friendly diet.

Moreover, flaxseed's antioxidant and anti-inflammatory properties may help reduce the risk of diabetes-related complications while improving overall metabolic health. However, further research is necessary to better understand its long-term effects, optimize dosage, and develop clearer dietary guidelines for clinical applications. Expanding our understanding of how flaxseed interacts with other dietary patterns and its underlying mechanisms will be a key to unlocking its full potential in diabetes management.

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