Original Article

Acute effect of flaxseed-enriched snack bars on glycemic responses and satiety in healthy individuals

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Background and Objectives: The dietary glycemic index (GI) and glycemic load (GL) have garnered scholarly attention for their roles in weight management and glycemic control. Flaxseed is a good source of fiber, lignans, and omega-3 fatty acids. This study evaluated healthy individuals' acute glycemic response and satiety following the consumption of flaxseed-enriched snack bars. **Methods and Study Design:** Nineteen healthy men and women consumed flaxseed bars or a glucose solution containing 50 g of available carbohydrates. Capillary blood glucose concentrations were obtained through the finger-prick test. The GI and GL values of the flaxseed bars were calculated using incremental area under the glucose response curve. Over 2 h, subjective satiety was examined at 0 (fasting), 15, 30, 45, 60, 90 and 120min following the consumption of flaxseed bars or saltine crackers containing 300 kcal by using a visual analogue scale (VAS). **Results:** Compared with that of the glucose solution, the glucose concentrations of the flaxseed bars (15–90 min) were significantly lower (p<0.001). The GI and GL values of the flaxseed bars were 30.0±23.0 and 2.3±0.2, respectively. Compared with saltine cracker consumption, flaxseed bars consumption resulted in lower hunger and higher satiety. The satiety index score of the flaxseed bars was 1.6 times higher than that of the saltine crackers. **Conclusions:** Although further studies are warranted to evaluate the long-term effects of flaxseed-enriched snacks on glycemia and energy balance, our findings suggest that the incorporation of flaxseed into snack bars is a viable strategy for the management of obesity and diabetes.

Key Words: glycemic index, glycemic load, satiety, flaxseed, snack bars

INTRODUCTION

Flaxseed (*Linum usitatissimum L.*), one of the oldest cultivated plants worldwide, is widely employed in the food industry. Studies have demonstrated that flaxseed confers numerous potential health benefits, including a reduction in the risk of developing chronic conditions (e.g., metabolic diseases, cardiovascular diseases, and cancers).[1-4] The bioactive components of flaxseed, including insoluble fiber, lignans, and flaxseed oil, may contribute to its positive effects.[5] For example, a recent clinical trial reported that the insoluble fiber in flaxseed lowered the body weight and improved the glycemic profiles of healthy individuals by delaying gastric emptying and reducing caloric intake.[6] In a model of streptozotocin-induced diabetes, the flax lignan complex delayed disease progression through antioxidant activities.[7] Furthermore, several in vivo studies have revealed that omega-3 fatty acids extracted from flaxseed oil slowed the progression of breast cancer and prostate cancer by modulating cell proliferation, inflammation, and oxidative stress signaling mechanisms.[8-10] Thus, flaxseed is considered a functional food and is employed in various types of food products. A flaxseed–water mixture is used to replace eggs in vegan baked goods such pancakes and muffins.[11] Microencapsulated flaxseed oil powder is incorporated into ice cream for the fortification of α-linolenic acid and the prevention of macronutrient and micronutrient deficiencies.[12] In combination with *Lactobacillus* and *Bifidobacterium*, flaxseed is added to beverages to enhance their nutritional value and to promote the uptake of lignans and flavonoids.

The glycemic index (GI) is used to classify carbohydrate-rich foods on the basis of the blood glucose response they induce. However, GI values do not always reflect glycemic effects, and they do not represent the content of available carbohydrates in foods.[13,14] In this context, to account for the quality and quantity of dietary carbohydrates consumed, the concept of glycemic load (GL) was introduced.[15]

Satiety, the feeling of fullness suppressing the sensation of hunger, can be measured through subjective ratings of hunger and fullness. Satiety plays an essential

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role in the management of caloric intake for health purposes. High satiety and low hunger are associated with reduced food intake.[16] Various studies have used satiety to predict subsequent food intake and to interpret eating behaviors.[17] Satiety is also widely employed for assessing the healthfulness of food. Studies have suggested that foods with a low GI or GL minimize spikes in blood glucose and insulin concentration, leading to reduced hunger and increased satiety.[18,19] Snacks that have a low GI or GL have been found to lower the risk of developing glucose intolerance, improve lipid metabolism, and help regulate body weight.[20-22]

Food composition is one of the major factors affecting satiety. For example, research has determined that the viscosity of soluble fiber is a key determinant of foods' satiating effects.[23,24] This is because soluble fiber slows both macronutrient absorption and the gastric emptying rate.[25] Various clinical trials have demonstrated that dietary supplements containing soluble fiber can promote satiety and lessen feelings of hunger.[26-28] Therefore, the use of soluble fiber as a functional ingredient in the production of healthy snacks will benefit the general population.

Recent research demonstrated that flaxseed can reduce blood glucose concentrations and stabilize blood glucose responses in healthy individuals.[29] However, whether flaxseed retains its blood-glucose-lowering effects when incorporated into snack bars remains unclear. Thus, this study evaluated the glycemic and satiety effects of flaxseed bars on healthy individuals.

METHODS

Participants

The study protocol was approved by the Institutional Review Board of the Nutrition Society of Shanghai. Written informed consent was obtained from the participants prior to study commencement. Nineteen healthy young individuals (8 men, 11 women) were recruited through the Shanghai University of Traditional Chinese Medicine. The participants were of normal weight (body mass index [BMI] 18.5–23.9), aged between 20 and 23 years, not pregnant or breastfeeding, and not receiving drug therapy. The main exclusion criteria were having a family history of diabetes or other metabolic disorders; having food allergies or intolerance to the treatment tests; having digestive, endocrine, or mental disorders; and being unable to tolerate at least 10 h of fasting.

Test foods

Food-grade anhydrous glucose (Xiwang Pharmaceutical Co., Ltd, Shandong, China) was used as a reference food for GI and GL calculations. The flaxseed bars were provided by Anhui NongAnkang Food Co., Ltd. Saltine crackers (Jiadun Food Co., Ltd, Hongkong, China) were used as reference food for testing satiety. Table 1 presents the nutritional information of the flaxseed bars and saltine crackers.

Study design

The study was designed as a randomized, placebo-controlled intervention. In the first experiment, the glycemic effects of flaxseed bars were examined. The participants were randomly assigned to either the control or intervention group and were instructed to follow their regular work and eating schedules for at least 3 days before the test. They were also asked to avoid eating foods high in dietary fiber and sugar for dinner. Fasting began after 10:00 p.m. the day before the test. On the morning of the test day, each participant was instructed to consume, at a comfortable pace but within 10 min, a 124-g flaxseed-enriched bar (containing 50 g of carbohydrates) or drink a glucose solution (250 mL of water into which 50 g of glucose had been dissolved). Subsequently, they were seated and not permitted to drink or eat anything with the exception of water for 120 min.

In the second experiment, to compare the subjective satiety of flaxseed bars or saltine crackers, 19 participants were asked to consume 300 kcal of flaxseed bars (68 g) or saltine crackers (63 g) within 10 min, on two mornings with a 3-day separation.

GI testing

The GI testing was conducted under an internationally recognized GI methodology.[30] By using the Accu-Chek Performa blood glucose meter (Roche Diagnostics, Shanghai Co., Ltd. China), capillary blood glucose concentrations were measured through the finger-prick test at 0 (fasting), 15, 30, 45, 60, 90, and 120 min following the start of consumption of the flaxseed bars or glucose solution. For each time point, two independent measurements were taken from each blood sample, and their average was designated as the blood glucose concentration.

As stipulated by the Food and Agriculture Organization and the World Health Organization, blood glucose responses were obtained as the area under the blood glucose curve (IAUC), and the area below the baseline was disregarded.[30] GI values were calculated as follows: GI = (IAUC for 50 g of carbohydrates from the flaxseed bars/IAUC for 50 g of carbohydrates from the glucose solution) × 100.[31] The GL of a flaxseed bar serving (90kcal) was computed as follows: GL = (GI of flaxseed bars × carbohydrate content of a flaxseed bar serving [g])/100.[15]

Subjective satiety assessment

Subjective satiety was assessed using a visual analogue

Table 1. Nutritional information of flaxseed-enriched snack bars and the saltine crackers

Product	Serving size (g)	Energy (kJ)	Carbohydrates (g)	Fiber (g)	Protein (g)	Total fat (g)	Polyunsaturated fatty acids (g)	Lignans (mg)
Flaxseed enriched snack bars	100	1994	34.4	11.8	21.4	25.7	18.8	155
Saltine crackers	100	1843	71.2	0	10	12.5	—	—

scale (VAS) for measuring hunger ("How hungry are you?") and satiety ("How satiated are you?") at 0 (fasting), 15, 30, 45, 60, 90, and 120 min following the first bite of a flaxseed bar or saltine cracker.[32] The items were scored from 0 (not at all) to 7 points (extremely). The raw score was then transformed according to a 0–100 scale. When marking the scores, the participants did not discuss or compare their scores with each other, and they did not refer to their previous scores. The satiety response was quantified as the IAUC over 120 min.

Statistical analysis

Individual participant data were normalized by subtracting the mean score of all the participants and dividing the result by the standard deviation of each time course. Data, presented as means and standard errors of the mean, were analyzed using GraphPad Prism version 7.0 (GraphPad Software Inc., CA, USA). Repeated measurements were used for between-group comparisons of postprandial glucose responses and satiety.

RESULTS

Participant characteristics

The characteristics of the participants are shown in Table 2. The mean age was 21.7±1.0 years, and the mean BMI was 20.5±1.9.

GI and GL of the flaxseed bars

Figure 1 presents the average postprandial glucose response curves. Normal variations in this response and the resulting GI values were observed among the participants. Specifically, the postprandial glucose response was significantly affected by time, treatment, and the time–treatment interaction (all $p<0.0001$). The postprandial blood glucose concentration increased to 6.8±0.74 mmol/L at 15 min and peaked at 8.39±0.87 mmol/L 30 min after the consumption of the glucose solution. The postprandial blood glucose concentration increased to 5.34±0.32 mmol/L at 15 min and peaked at 5.73±0.51 mmol/L 30 min after the ingestion of the flaxseed bars. Compared with the glucose solution, the flaxseed bars resulted in significantly lower postprandial glucose concentrations from 15 to 90 min.

The mean GI of the flaxseed bars was 30.0±23.0. A serving size of the flaxseed bars (90 kcal) contains 7.6g digestible carbohydrates, leading to the GL value of 2.3±0.2. Under the ISO 2010 method for GI and GL determination, the flaxseed bars are considered a low-GI (<55) and low-GL (<10) food.

Subjective satiety following the consumption of flaxseed bars and saltine crackers (iso-caloric portions)

Figure 2 presents the hunger and satiety effects reported after the consumption of iso-caloric portions (300 kcal) of flaxseed bars and saltine crackers. An overall time ($p<0.001$), treatment ($p<0.05$) and interaction ($p<0.05$) effects on VAS scores were observed for the subjective hunger and satiety between the two groups. Moreover, the satiety index of the flaxseed bars was 161±23.6. Flaxseed bar consumption was associated with significantly higher satiety compared with the saltine crackers ($p<0.05$) at 60 min.

DISCUSSION

The amount and type of carbohydrates consumed are the major dietary factors that control blood glucose responses. Epidemiological studies have reported that the intake of high-GI and high-GL food is associated with higher risks of the development of chronic conditions such as type 2 diabetes, cardiovascular diseases, and certain cancers.[33-35]

Table 2. Baseline characteristics of the participants[†]

	All (n=19)	Men (n=8)	Women (n=11)
Age (years)	21.7±0.2	22.3±0.4	21.3±0.2
Height (m)	1.69±0.02	1.74±0.02	1.65±0.05
Weight (kg)	58.8±1.9	65.3±2.8	54.2±1.7
BMI (kg/m^2)	20.5±0.4	21.6±0.6	19.8±0.5

[†]All data were presented as mean±SE.

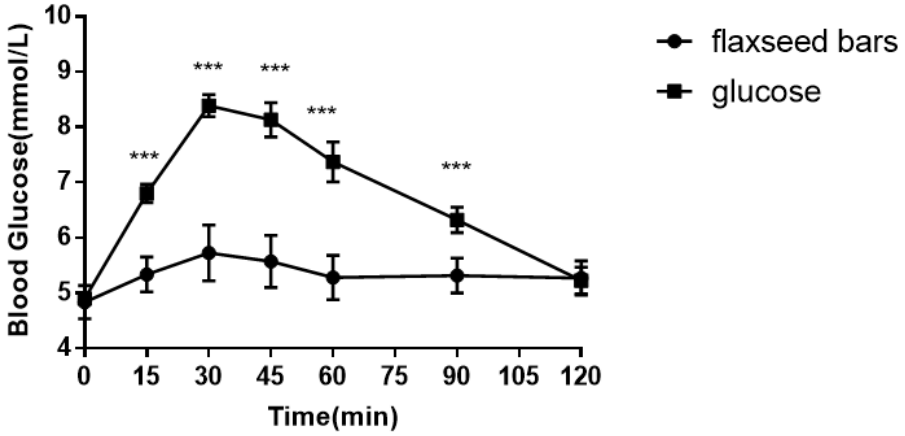

Figure 1. Postprandial glucose response curves in healthy participants following the consumption of 50 g of available carbohydrates from a glucose solution or flaxseed-enriched snack bars. Data are expressed as means ± standard errors of the mean (n=19). *** $p<0.001$.

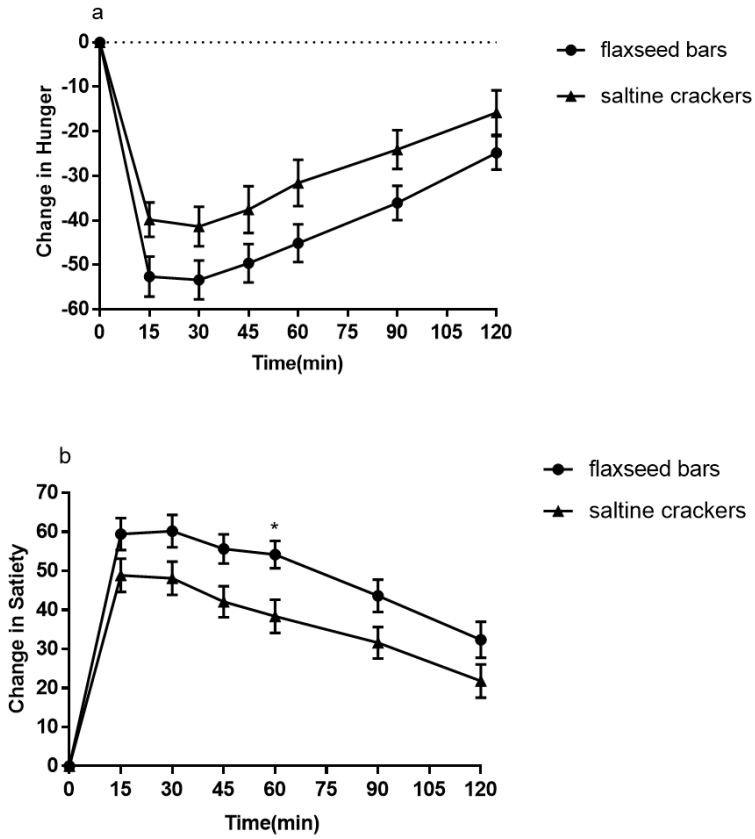

Figure 2. VAS scores of satiety following the consumption of flaxseed-enriched snack bars or saltine crackers. VAS profiles are shown for hunger (a) and satiety (b). Data are expressed as means ± standard errors of the mean (n=19). $^{*}p<0.05$.

Thus, GI and GL constitute useful indicators for guiding the selection of healthy food choices. As previously mentioned, the GI and GL of the flaxseed bars were 30.0±23.0 and 2.3±0.2 respectively, meaning that the bars can be classified as low GI and low GL. Given that flaxseed constituted 60 g of a 100-g serving of the flaxseed bars employed, the low postprandial glycemic effect of the bars is likely attributable to the flaxseed they contained rather than to other ingredients. Consistent with our findings, a recent study observed lower hemoglobin A1c concentrations in individuals with type 2 diabetes who consumed 200 g of yogurt containing 2.5% fat and 30 g of flaxseed over 8 weeks.[36]

Clinical trials have indicated that flaxseed supplementation can improve the blood glucose management of patients with prediabetes, type 1 diabetes, and type 2 diabetes.[37,38] The numerous bioactive components of flaxseed may contribute to its antihyperglycemic effects. Flaxseed contains approximately 30% dietary fiber, including soluble fiber (mucilage gum) and insoluble fiber.[39] The flaxseed bars tested in the present study contain 11.8 g of dietary fiber per 100-g serving; this may be a major reason for the management of glycemic control observed in the participants. Furthermore, the lignans or polyunsaturated fatty acid content of flaxseed may help lower blood glucose concentrations. We estimate that the flaxseed bars contain 154.6 mg of lignans and 18.8 g of polyunsaturated fatty acids per 100-g serving. These estimations are based on the publication that the reporting lignan concentrations are 257.6 mg per 100-g and the flaxseed bars contain 60% flaxseed.[40,41] Moreover, about 73% of the fatty acids in flaxseed are poly-unsaturated.[41] An animal study demonstrated that lignans in flaxseed can control blood glucose concentrations by inhibiting pancreatic alpha-amylase or by increasing the sensitivity and response of target cells to insulin.[42] Another investigation found that the omega-3 fatty acids in flaxseed reduces blood glucose and hemoglobin A1c concentrations and mitigates the severity of type 2 diabetes by regulating the gut microbiota in rats. Those findings support the premise that flaxseed consumption helps lower serum blood glucose.[43]

With the increase in general concern about health, consumer demand for functional foods has grown substantially in recent years. However, some researchers question the effectiveness of functional foods after they are combined with general foods. A recent study demonstrated that compared with snack bars without additional fiber, snack bars containing various amounts of oat and barley beta glucan did not lead to reductions in postprandial blood glucose concentrations.[44] However, we found that flaxseed exerted a significant impact on the participants' postprandial blood glucose concentrations when consumed in snack bars, a type of baked good. This discrepancy may be due to the physicochemical properties of the fiber and their distinct behavior within a solid food matrix. For example, studies have indicated that the baking process does not significantly affect the bioavailability of flaxseed components such as fatty acids or lignans.[38,45] In another investigation, the incorporation of 5% ground flaxseed into baked goods increased the antioxidant activity of such goods.[46] Thus, flaxseed-fortified snack bars may constitute a favorable option for individuals seeking

to manage their postprandial blood glucose concentrations.

Satiety is a pivotal factor influencing overconsumption and is associated with reduced energy intake at the next meal. Compared with the saltine crackers, the flaxseed bars led to stronger feelings of satiety and weaker feelings of hunger, with a satiety index of 170%. Our results accord with those of another study demonstrating that dietary fiber in flaxseed significantly suppressed appetite in healthy individuals.[47] The increased viscosity in the soluble fiber can delay gastric emptying and promote the release of satiety hormones.[48] Herein, the consumption of the flaxseed bars (relative to that of the saltine crackers) resulted in greater satiety at 60 min. The difference in duration may be due to between-study variations in the amounts and composition of macronutrients in the snack bars examined. A 50-g serving of the flaxseed bars we tested contains 5.9 g of fiber. Further research is warranted to analyze the effects of flaxseed-enriched snack bars on insulin responses and concentrations of gastrointestinal hormones such as ghrelin, glucagon-like peptide 1, and gastric inhibitory polypeptide.

With the high prevalence of obesity, an effective strategy for appetite control and energy balance is necessary. Traditional snack bars contain saturated fat and added sugar. Healthy, nutritionally balanced snack bars have gained increasing attention in recent years.[49] A study observed that the mid-morning consumption of healthy snack bars high in protein and fiber significantly reduced food intake at lunch compared with the mid-morning consumption of isocaloric snack bars high in fat and refined carbohydrates.[50] Compared with saltine crackers, the present flaxseed bars have higher concentrations of protein and fiber and lower concentrations of carbohydrates. Although the bars contain more fat than the crackers, this fat primarily consists of polyunsaturated and monounsaturated fatty acids due to the properties of flaxseed.[51] Notably, a study determined that the incorporation of flaxseed into baked goods did not alter the consumption preferences of baked goods by the general population.[46]

Conclusion

Flaxseed-enriched snack bars reduced postprandial blood glucose concentrations and promoted subjective satiety in healthy adults. The incorporation of flaxseed might be a viable-strategy for enhancing the nutritional value of snack bars. However, further studies are necessary to evaluate the long-term effects of flaxseed bars on glycemia and energy balance. In addition, investigations into the effects of combinations of flaxseed-enriched bars with other foods on glycemia and satiety are warranted.

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AUTHOR DISCLOSURES

None of the authors have any other personal or financial conflicts of interest.

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