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Does flaxseed and chia use affect postprandial glucose, insulin and subjective saturation response in healthy individuals?

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Ethics Committee Approval
The study was approved by the Toros University Clinical Research Ethics Committee on February 5, 2020 (number: 2020/80).
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

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Abstract

Background/Aim: In recent years, there has been an increase in the prevalence of obesity and its complications, along with a growing awareness of healthy nutrition. As a result, consumers are seeking to incorporate more functional foods into their diets. Chia and flax seeds have gained popularity due to their soluble fiber and antioxidant capacity. This study aims to compare the effects of consuming cakes made with the addition of chia and flax seeds on blood glucose and insulin levels, as well as evaluate their impact on post-consumption satiety response in individuals.

Methods: This randomized, double-blind, self-controlled experimental study involved 12 volunteers (19–64 years old) who were free from acute or chronic diseases. The participants had a body mass index (BMI) value between 18.5 and 24.9 kg/m^2 and a Beck Depression Inventory score of 8 or below. The study investigated the effects of standard and test cakes containing 50 g of digestible carbohydrates, including chia-added cake, flaxseed-added cake, and chia+flaxseed-added cake. Postprandial blood sugar, insulin, and subjective satiety responses were assessed. A standard nutrition program (diet: 60% carbohydrates, 20% protein, 30% fat) was implemented at least one week before the study, and participants were asked to maintain 24-h food consumption records the day before the test days. Throughout the study period, individuals were instructed to avoid caffeine, medication, nutritional supplements, and heavy physical activity. Cake consumption sessions were conducted at the research center, with participants visiting four times in total, with at least 1-week intervals. Fasting for 10–12 h prior to each visit, saturation responses were measured using a visual analog scale at 0, 15, 30, 60, 90, 120, and 180 min. Blood samples were also collected to assess blood glucose and insulin levels.

Results: The study revealed that cakes containing chia and flaxseeds, compared to the standard cake, as well as flaxseed-added cake compared to chia-added cake, resulted in higher plasma glucose under-curve values and saturation responses and lower hunger responses (P=0.038, P=0.016, P=0.004, respectively).

Conclusion: The findings indicate that both chia and flax seeds impact glycemic control and the sensation of satiety, with flaxseed exhibiting greater effectiveness than chia.

Keywords: chia, flaxseed, blood glucose, insulin, appetite

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Introduction

In recent years, there has been a rise in the prevalence of obesity and its associated complications. Concurrently, there has been an increased awareness of healthy nutrition and a growing desire among consumers to lead healthy lives. As a result, individuals seek to obtain essential nutrients and health benefits from their food choices. This has led to a greater demand for functional foods in their diets [1].

Chia seeds (*Salvia hispanica* L.) and flaxseeds *(Linum usitatissimum*) are edible oilseeds/grains. The United States Nutrition Guidelines, published in 2000, recommend a daily consumption limit of 48 g for chia seeds in adults, considering potential gastrointestinal complaints. The recommended daily consumption amount for flaxseeds is less than 40 g [2,3].

According to data from the United States Department of Agriculture Research Service (USDA) in 2017, chia seeds contain 30.7% lipid, 16.5% protein, and 34.4% fiber, while flaxseeds contain 30–45% lipid, 20–25% protein, and 28% fiber [4-6]. Functional fibers are plant-based components that exhibit specific properties and undergo partial or complete fermentation in the colon. These fibers can be classified into two groups based on their water solubility: soluble and insoluble [7]. Most fibers found in chia and flaxseeds belong to the soluble fraction [8]. These seeds have gained popularity as functional foods due to their antioxidant capacity, particularly their soluble fiber content, and the presence of omega-three fatty acids [9,10].

The soluble fibers present in these seeds contribute to delayed gastric emptying by increasing the viscosity of gastric content and prolonging gastrointestinal transit time. As a result, carbohydrate absorption is slowed, the glycemic index is reduced, insulin release is slowed, and feelings of satiety are enhanced by the increased viscosity of the small intestine contents. These properties make these seeds useful in the nutritional management of obesity and its related complications [8].

While the most effective approach to combat obesity is long-term energy intake that is lower than energy expenditure, adherence to long-term energy-restricted diets is often low [11]. Foods enriched with chia and flax seeds offer an alternative option in the battle against weight loss. They contain increased amounts of soluble fiber, protein, and minerals, as well as α-linolenic acid and phytochemicals, which can aid in treating obesity and its complications, including inflammation [11].

Although using chia and flax seeds in the food industry, particularly in heat-treated products, is uncommon, these seeds have various commercial applications [12].

While studies investigating the impact of consuming products incorporating these seeds, which are gaining popularity as functional foods, on biochemical parameters are not widely available in the literature, a recent study examined the effect of chia seeds on body weight in mildly overweight and obese individuals with type 2 diabetes. The results indicated that the group consuming chia seeds demonstrated improved glycemic control, greater weight loss, and reduced waist circumference [13].

In another study, which assessed the effects of supplementing 10 g/day of flaxseed for one month in individuals with type 2 diabetes, it was found that flaxseed significantly reduced fasting and three-month blood glucose levels [14]. However, a contrasting study conducted in the United States reported that flaxseed improved glycemic control [15].

In this study, we aim to investigate the impact of chia and flax seeds on glycemic control, insulin levels, and satiety response. By examining these effects, we aim to promote the use of alternative products incorporating these seeds in obesity management, as well as weight loss programs and the prevention of obesity-related complications. Specifically, this study aims to evaluate the effects of cakes supplemented with chia and flax seeds, which can be easily prepared at home and are regarded as popular and healthy snack alternatives, on postprandial blood glucose, insulin levels, and individuals' satiety responses.

Materials and methods

Study design

This randomized, double-blind, self-controlled experimental study was conducted at Mersin Forum Yaşam Hospital between May and June 2022. The study included 12 individuals aged 19 to 64 who were free from acute or chronic diseases, had a body mass index (BMI) value between 18.5 and 24.9 kg/m^2, and had a Beck Depression Inventory score of 8 or below. Participants who were using prescription drugs and/or fiber supplements, following a specific diet, pregnant or lactating, consuming excessive alcohol (more than two drinks per day), experiencing menstruation, diagnosed with gluten enteropathy, or had previously experienced an allergic reaction to chia and flax seeds were excluded from the study.

To establish the nutritional standard for the study, a standardized nutrition program was implemented at least one week before the study. The program included a diet comprising 60% carbohydrates, 20% protein, and 30% fat. Participants were provided with this program, and their 24-h food consumption records from the day before the test days were evaluated using the Nutrition Information System (BEBIS) 8.2 software [16]. Throughout the study period, participants were instructed to refrain from consuming caffeine, medication, or any nutritional supplements and to avoid engaging in strenuous physical activity, as these factors could potentially affect the results.

To determine the sample size, a power analysis was conducted using G*Power software. The analysis utilized alpha (α) set at 0.05, power (1-β) set at 0.80, and a medium effect size (d) of 0.50. The results indicated that a minimum of six individuals per group were required. To account for potential issues such as withdrawals and irregular participation, the study initially enrolled 14 volunteers. However, two individuals withdrew voluntarily in the subsequent weeks. Random assignment of participants who met the inclusion and exclusion criteria was performed by the principal researcher using the R programming language in a computerized environment. Ethical approval for this study was obtained from the Mersin University Clinical Research Ethics Committee on February 5, 2020 (number: 2020/80), and written informed consent was obtained from all participants before their participation. This study has been registered at ClinicalTrials.gov under the identifier NCT05358561.

The study consists of two stages. The first stage involved conducting sensory analyses on the standard and test cakes, which were integral to the background study. Based on the results of this analysis, the selection of cereal-like products to be used in the test cakes was determined. Additionally, nutritional analyses were performed during this stage to ascertain the quantities of the standard and test cakes that contained 50 g of digestible carbohydrates (cakes with added chia seeds, cakes with added flaxseeds, and cakes with added chia and flaxseeds). These cake variations were finalized based on the sensory analysis results. The second stage of the study aimed to investigate the effects of these cakes on postprandial blood glucose, insulin, and subjective satiation response in the participants.

Making the cakes and their contents

To determine the quantities of the standard cake (with ingredients: egg 30 g, sugar 19.3 g, sunflower oil 36 g, vanilla 0.75 g, baking powder 0.75 g, wheat flour 40 g, cow's milk 28.5 g) and the test cakes prepared in addition to the standard recipe (chia seed-added cake 15 g, flaxseed-added cake 22.5 g, chia and flaxseed-added cake 9 g each) that would contain 50 g of carbohydrates, various analyses were conducted on samples taken from each of the four cake types in the Food Chemistry Laboratory at Toros University. These analyses included protein, fat, moisture, ash, total fiber, and soluble fiber analyses. Based on the obtained results, the amounts of cakes containing 50 g of digestible carbohydrates were calculated. The cakes were then weighed and prepared for individual consumption one day before the study (Table 1).

The quantities of chia and flax seeds added to the cakes for the study were calculated to ensure that the total fiber content remained consistent and within the recommended daily consumption limits, as stated in the literature [2, 3]. Both chia seeds (Köryusuflar, Mersin) and flax seeds (Köryusuflar, Mersin) were sourced from local markets.

Nutritional analysis of cakes

Moisture Analysis: The moisture analysis of cake samples will be performed after the cakes have been baked and cooled for one hour. The moisture content (%) will be calculated based on the weight difference resulting from drying in an oven at 105ºC until a constant weight is achieved [17].

Ash Analysis: The ash analysis of cakes will be carried out according to Association of Official Analytical Chemists (AOAC) 1990 [18]. The samples will be weighed in porcelain crucibles that have been previously brought to a constant weight and burned in a muffle furnace (Elektro-mag M1813, Turkey) at 550 ± 5ºC until the residue turns white. The ash content (%) of the cakes will be calculated by proportioning the sample mass remaining in the crucibles at the end of the incineration process to the initial sample mass.

Protein Analysis: In the protein determination by the Kjeldahl method, the total amount of nitrogen contained in the food is determined. The protein content (%) will be determined by multiplying the total nitrogen amount determined by the nitrogen factor, which is determined according to the total organic nitrogen ratio in the protein molecule [19,20].

Fat Analysis: The fat analysis will be carried out using the Soxhlet method according to AOAC 1990 [17]. For fat determination, approximately 4 g of cake sample will be weighed into a cellulose cartridge, covered with cotton wool, and placed in the Soxhlet apparatus. At the end of the extraction using petroleum ether, the ether in the balloons will be evaporated, and the fat content in the sample will be calculated.

Fiber Analysis: The dietary fiber content of the cakes will be determined according to American Association of Cereal Chemists (AACC) 2000 [21]. Samples for dietary fiber analysis will be subjected to enzymatic digestion with heat-resistant enzymes α-amylase, protease, and amyloglucosidase (Sigma-Aldrich, St. Louis, MO, USA) to remove starch and protein. The enzyme-digested material will then be treated with alcohol to precipitate soluble dietary fiber before filtration. The dietary fiber residue will be washed with water, then acetone, dried, and weighed.

Soluble Fiber Analysis: The dietary fiber contents of cake samples were determined according to AOAC 991.43 [22] using the Megazyme analysis kit. The samples were treated with α-amylase (30 min, 100°C), protease (30 min, 60°C), and amyloglucosidase (30 min, 60°C) enzymes, respectively, to remove starch and protein molecules from the structure. The resulting mixture was filtered with a Gooch crucible. The solid portion remaining at the top of the crucible was washed with distilled water, ethanol (95%), and acetone (99%) and then dried at 105 °C for 3 h. The ash and protein contents of the dried samples were determined, and the insoluble dietary fiber was calculated. Soluble dietary fibers were precipitated and filtered by adding four times the volume of ethanol (95%) to the filtrate obtained from the filtration process. The precipitate was washed with 78% and 95% ethanol and acetone, respectively, and dried to a constant weight, and the residue was analyzed for ash and protein to determine the amount of soluble dietary fiber.

The soluble fiber analysis of the cake samples, using 100 g portions, revealed the following findings: the standard cake made with 40 g of wheat flour (100% wheat flour) contained 2.32 g of soluble fiber, while the cake prepared with 64.0 g of wheat flour and 36% flaxseed (equivalent to 22.5 g of flaxseed) contained 2.95 g of soluble fiber. Furthermore, when analyzing the cake (15 g) with chia added (composed of 72.4% wheat flour and 27.6% chia), it contained 0.65 g of soluble fiber. Based on these results, it can be concluded that flaxseed exhibits a notably high soluble fiber content, containing approximately 4.5–5 times more soluble fiber than chia (Table 1).

Table 1: Quantity and nutritional value of test cakes.

Nutritional values	Standard cake	Chia-added cake	Flaxseed-added cake	Chia+flaxseed-added cake
Quantities of cakes	142.3	114.9	140.2	120.8
Carbohydrate (g)	50.0	50.0	50.0	50.0
Total fiber (g)	1.7	6.8	6.8	6.8
Soluble fiber (g)	2.32	<0.65	2.95	<0.65
Protein (g)	11.6	11.5	12.9	10.9
Lipid (g)	34.2	16.7	40.4	28.5
Moisture (g)	43.4	36.5	36.2	30.4
Ash (g)	3.12	0.33	1.16	1.06
TPC (mg gallic acid/L)	271	289	328	334
Aox (mmol trolox/g)	0.151	0.155	0.247	0.200

Aox: Antioxidant; TPC: Total phenolic content

Consumption and evaluation of cakes

The participants involved in the study visited the research center on four separate occasions, with at least 1-week intervals between visits, to consume their assigned cakes. On the test day, the individuals were required to fast for 10–12 h before they arrived at the research center, during which time they were only permitted to drink water. Furthermore, as the study was conducted double-blind, both the participants and the researchers responsible for cake production and distribution were unaware of the specific cake types. The cakes were identified solely by their assigned codes. Upon arrival, the fasting and appetite responses of the participants were assessed using a 100-mm Visual Analog Scale (VAS), and fasting venous blood samples were collected to measure blood glucose and insulin levels. Subsequently, the participants consumed the cakes within a 10-min timeframe. VAS measurements of appetite responses were recorded at the 15th, 30th, 60th, 90th, 120th, and 180th min following cake consumption, and additional venous blood samples were taken during these 3 h. Throughout this time, the participants were instructed not to leave the research center or consume any other food.

Biochemical parameters and saturation responses

Glucose values were analyzed using the glucose hexokinase enzymatic reference method (Cobas 501), while insulin values were analyzed using the electrochemiluminescence (ECL) method (Cobas 601).

The VAS converts certain non-numerical values into digitized measurements. The parameter being assessed is represented by two definitions placed at the ends of a 100 mm line, and participants are instructed to indicate their respective position by assigning corresponding numbers [23]. In this study, the VAS was employed to gauge individual responses to hunger, satiety, desire for prospective food consumption, perception of sweetness, taste satisfaction (deliciousness), saltiness, and fattiness at the 15th, 30th, 60th, 90th, 120th, and 180th minutes. This allowed for the acquisition of numerical values.

Sensory analysis results

Panelists evaluated the sensory analyses of the cake samples following the pre-test productions. In the pre-test productions, a total of eight different cakes, along with a standard cake, were produced. These cakes were made using varying proportions of chia seeds, flaxseeds, buckwheat, and combinations thereof. The sensory properties of the samples were assessed based on color, texture, taste, appearance, and overall taste. The analysis revealed that the utilization of cereal-like products did not have a statistically significant impact on any sensory quality of the cake samples.

Consequently, it was concluded that all cake samples were equivalent in terms of sensory quality, and the inclusion of cereal-like products did not adversely affect the overall quality. However, it was noted that cake samples containing buckwheat were preferred in terms of volume, although the panelists described the presence of hard particles in their mouths when consuming the buckwheat-added samples as a negative experience. Therefore, the effect of buckwheat was not further examined in the study. While no statistical differences were observed among the samples, the first three samples, excluding the control sample, were selected for further investigation based on their general taste. The study aimed to explore the effects of chia and flax seeds used in these selected samples.

Regarding general taste, the cakes that incorporated both chia and flax seeds received the same score as those that solely used chia seeds. However, the samples that utilized both seeds together were the most preferred in terms of color. In a study conducted by Shaikh et al. [24], it was stated that cupcake samples containing a 10% mixture of chia and flax seeds achieved a color and appearance similar to that of the control sample. These samples also exhibited comparable texture, taste, smell, and general acceptability. Lipilina and Ganji [25] reported that using flaxseed improved the color of muffin samples, with higher scores given to samples containing a greater ratio of flax seeds. Cake samples made exclusively with chia seeds received higher scores for their porous structure and taste characteristics than the other samples. Chelladurai et al. [26] indicated that incorporating chia seeds into cookie recipes, with increasing concentrations, enhanced sensory properties such as color, appearance, texture, taste, smell, and overall acceptability. Steffolani et al. [27] demonstrated that including chia seeds enhanced the taste, texture, and appearance of gluten-free bread. Regarding texture, cake samples using only flaxseed received the highest score. Pohjanheimo et al. [28] reported that flaxseed bread was softer and more elastic than the control samples. Consistent with the findings of this study (Table 2), several researchers have reported that the inclusion of chia and flax seeds in bakery and pastry products does not significantly impact the overall acceptability of the samples in terms of sensory evaluation [25,27,29-32].

Table 2: Sensory parameters of cake samples.

Cakes	Color	Texture	Flavor	Appearance		General taste
				Volume	Porous structure	
Standard	3.9 (1.1)†	4.0 (1.0)†	3.6 (1.1)†	3.3 (0.9)†	3.9 (0.4)†	3.9 (0.4)†
Chia-added	3.7 (1.3)†	4.1 (0.7)†	3.9 (0.9)†	4.1 (1.2)†	4.0 (0.6)†	4.0 (0.6)†
Flaxseed-added	4.0 (1.4)†	4.3 (0.9)†	2.9 (1.3)†	4.1 (0.4)†	3.9 (1.1)†	3.9 (1.1)†
Chia+Flaxseed-added	4.6 (0.5)†	4.1 (1.5)†	3.0 (1.3)†	4.1 (1.1)†	4.0 (1.2)†	4.0 (1.2)†

† There is no difference between the groups with the same letter

Statistical analysis

During the hypothesis testing phase of the study, the suitability of variables for normal distribution was determined using the Shapiro-Wilk test. For variables that met the assumption of normal distribution, the analysis of variance (ANOVA) test was employed for comparisons among three or more independent groups. When the assumption of sphericity was met, the Sphericity Assumed test statistic was utilized. In cases where the sphericity assumption was not met, the Greenhouse-Geisser test statistic was employed. The Bonferroni correction paired t-test, and Tukey test were used for multiple comparisons between groups and yielded significant results. A margin of error of 5% was set for statistical analysis. Graphs and the calculation of the area under the curve (AUC) were performed using the R-Project program [33], while all other analyses were conducted using SPSS (IBM SPSS Statistics 26). The significance level was set at *P*-value <0.05.

Results

Table 3 presents the AUC values for time-based plasma glucose and insulin levels following the consumption of the test cakes by study participants. Upon examining the results, it was observed that the AUC values for plasma glucose were higher after consuming cakes with added chia and flaxseeds compared to the standard cake (P=0.038). Furthermore, it was found that the AUC values for plasma glucose were significantly higher after consuming flaxseed-added cake compared to chia-added cake. However, there was no significant difference in plasma insulin levels and AUC values (P=0.237).

Table 3: Comparison of the area under the curve of plasma glucose and insulin levels of individuals consuming cake based on time.

AUC values	Flaxseed-added cake n=12	Chia-added cake n=12	Chia+flaxseed-added cake n=12	Standard cake n=12	*P*-value
Glucose	2992.7¶	2681.4 ¶††	2724.1 ¶††	2637.1††	0.038 †§*
Insulin	954.2	1118.9	1035.9	1167.2	0.237 †‡

AUC: Area Under the Curve, †: ANOVA, ‡: Sphericity Assumed, §: Greenhouse-Geisser, ¶††: No difference between groups with the same symbol; *P<0.05; **P<0.001

Figure 1 illustrates a line chart depicting the changes in plasma glucose and insulin levels over time following cake consumption by the participants.

Figure 1: Plasma glucose and insulin levels based on time after cake consumption of individuals.

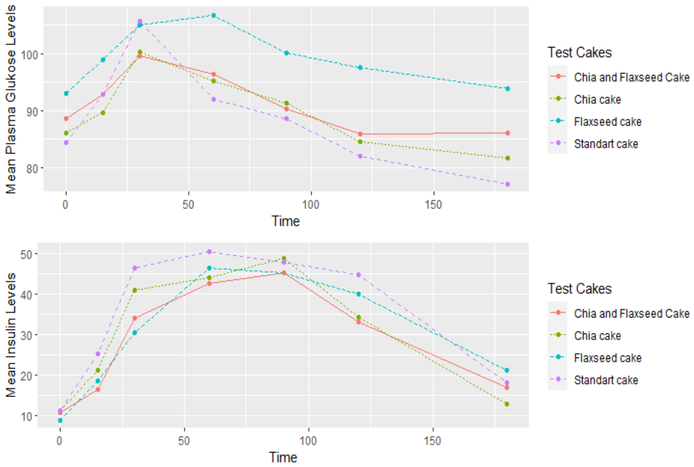


Table 4 presents the AUC values on the VAS for different aspects related to cake consumption by the study participants. Statistical analysis revealed significant differences in hunger, satiation, and craving for sugary, delicious, salty, and fatty foods after cake consumption (P=0.004, P=0.016, P=0.007, P=0.027, P=0.028, P=0.035, respectively). Hunger levels were found to be lower (P=0.004), and satiation levels were higher (P=0.016) after consuming flaxseed and chia-added cakes compared to the standard cake. Furthermore, when comparing the individuals who consumed flaxseed cake with those who consumed chia-added cake, it was observed that the former group experienced less hunger (P=0.004) and greater satiation (P=0.016).

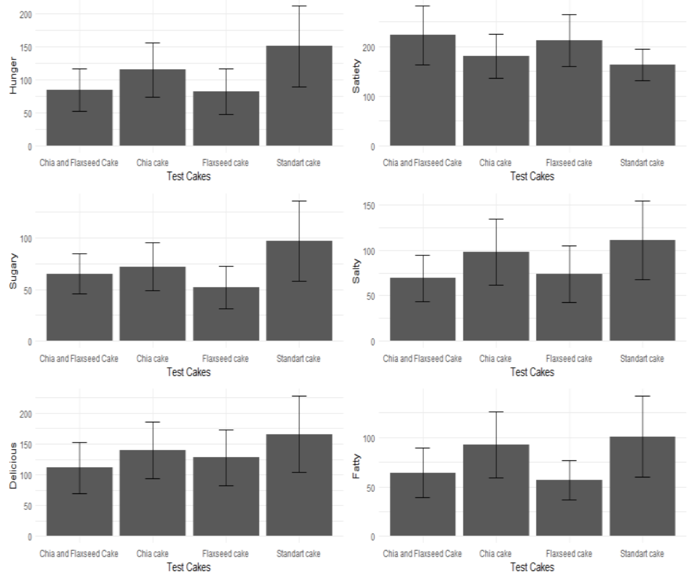
Table 4: Comparison of VAS area under the curve values of individuals consuming cake.

AUC values	Flaxseed-added cake n=12	Chia-added cake n=12	Chia+flaxseed-added cake n=12	Standard cake n=12	*P*-value
Feeling of Hunger	82.083††	114.792¶††	84.792¶††	150.521¶	0.004†‡*
Feeling of Saturation	223.438††	180.417¶††	212.396¶††	163.438¶	0.016†‡*
Desire to eat	114.896	121.771	82.708	129.688	0.064†§
The level of desire to eat	100.413	121.667	79.688	133.542	0.089†§
Desire to consume sugary foods	65.208¶††	71.979¶††	51.979††	96.979¶	0.007†‡*
Desire to consume salty foods	69.167††	98.125¶	73.646¶††	111.042¶††	0.028†§*
Desire to consume delicious foods	111.146††	139.687¶	128.021¶††	165.937¶††	0.027†§*
Desire to consume fatty foods	64.167¶††	92.813¶	56.771††	100.833¶††	0.035†§*

AUC: Area Under the Curve, †: ANOVA, ‡: Sphericity Assumed, §: Greenhouse-Geisser, ¶††: No difference between groups with the same symbol; *P<0.05; **P<0.001

Figure 2 presents a bar graph representing the AUC measured on the VAS after cake consumption by the individuals.

Figure 2: VAS under-curve area values after cake consumption of individuals.



Discussion

This study demonstrates that consuming chia and flaxseed positively affects glycemic control and the feeling of satiety. However, its impact on insulin secretion is negligible. Furthermore, it suggests that flaxseed exhibits a stronger effect than chia, which may prompt further investigation into this topic.

Chia and flax seeds are widely consumed in many countries and have gained recognition as functional foods. They are valued for their positive effects on glycemic control, antioxidant content, and anti-inflammatory properties [13,34]. The primary mechanism through which chia and flax seeds influence glycemic control is by virtue of the soluble fibers they contain. These fibers increase stomach and small intestine viscosity, delaying gastric emptying and prolonged gastrointestinal transit time. Consequently, the absorption of carbohydrates is delayed, resulting in reduced glycemic response, delayed insulin release, and increased satiety [8]. Moreover, lignan, one of the three primary phytoestrogens found in these seeds, aids in glycemic control by suppressing the expression of the phosphoenolpyruvate carboxykinase (PEPCK) gene responsible for glucose production through gluconeogenesis, thus inhibiting glucose production [35]. Furthermore, the alpha-linolenic acid (ALA) content of these seeds contributes to glycemic control through improved insulin sensitivity [36,37].

In a study involving mildly overweight and obese individuals with type 2 diabetes, it was observed that daily consumption of 30 g/1000 kcal of chia seeds, along with an energy-restricted diet, resulted in improved weight loss and postprandial glycemia levels [13]. Similarly, a study conducted with healthy individuals found that the consumption of each 1 gram of chia seeds led to a 2% decrease in postprandial glycemia, slowed carbohydrate release, and reduced appetite response [12]. Numerous randomized controlled clinical trials have been carried out to assess the effectiveness of flaxseed or its derivatives in glycemic control and insulin sensitivity [10,38,39]. While some studies have reported the beneficial effects of flaxseed, others have found no significant benefits [14,40-42]. Inconsistencies in these findings have been attributed to variations in sample sizes and intervention durations among the target populations.

This study observed that the plasma glucose AUC values, measured after consuming cakes with added chia and flaxseeds, were higher than the standard cake. Additionally, the plasma glucose AUC values were higher in the flaxseed-added cake than the chia-added cake. Despite the similar nutritional composition of the chia and flaxseed-added cakes, these differences in postprandial glycemia can be attributed to the higher content of soluble fiber found predominantly in the seeds. This finding aligns with existing literature, as flaxseed contains, on average, five times more soluble fiber than chia on a gram-to-gram basis [42-45].

The consumption of chia and flaxseed also has a positive impact on insulin secretion, supported by several mechanisms. Firstly, the soluble fiber content in these seeds slows down glucose absorption, reducing the need for insulin production. Secondly, their antioxidant content can enhance insulin sensitivity [15,46]. Additionally, the protein content of these seeds has been shown to stimulate insulin secretion, while the ALA content can contribute to increased insulin sensitivity [36,37,47]. A recent meta-analysis demonstrated that flaxseed significantly decreased insulin secretion in interventions lasting 12 weeks or more but not in shorter interventions [48]. These findings were further supported by another study that investigated the effects of flaxseed supplementation on blood glucose and insulin resistance in individuals with obesity and insulin resistance over a 12-week intervention period [49]. Possible explanations for these time-dependent intervention results include a gradual increase in ALA, which can be converted to long-chain fatty acids such as EPA (Eicosapentaenoic acid; 20:5, n-3) and DHA (Docosahexaenoic acid; 22:6, n-3), improving insulin sensitivity and glycemic control. Additionally, improvements in gut flora, brought about by the consumption of soluble fiber, may contribute to enhanced glycemic control [50-53]. This study found no significant difference in the plasma insulin AUC values between individuals consuming cakes with added chia or flaxseeds and those consuming the standard cake. This lack of significant difference can be attributed to the short intervention period in the study design.

Consuming soluble fiber has been linked to a sensation of satiety and its potential impact on food intake [54]. Insufficient satiety significantly contributes to increased caloric intake and the high prevalence of obesity and its associated complications [55]. The effect of consuming soluble fiber on the feeling of satiety is attributed to its ability to form a gel-like structure in the stomach during digestion, leading to increased gastric distension and triggering satiety signals through the afferent vagus nervous system [56,57]. Furthermore, soluble fiber consumption has been shown to modulate the secretion of gastrointestinal (GI) hormones involved in appetite regulation [58]. Several studies have demonstrated that consumption of soluble fiber, typically in doses exceeding 5 g, increases the production of satiety-regulating GI hormones such as glucagon-like peptide 1 (GLP-1) and Peptide YY (PYY) [59-61]. Additionally, it has been suggested that soluble fiber consumption may harm levels of ghrelin, the hormone commonly known as the "hunger hormone," in healthy adults [60,62,63].

In a study assessing the effects of flaxseed on satiety, it was observed that adding 5–15 g of flax mucilage (equivalent to approximately 50–150 g of whole ground flax) to baked goods did not significantly impact satiety parameters. However, adding 2.5 g of flax mucilage (equivalent to 25 g of ground flax) to a beverage resulted in decreased satiety and general appetite [64-66]. Another study involving bread containing 24 g of chia seeds found that chia-added bread led to a greater sense of fullness after 120 min compared to control white bread [67]. While the effect of soluble fiber enrichment on satiety has mainly been studied in cereal derivatives, generally positive associations have been reported in various populations, including obese individuals and those with cardiometabolic risk [68,69]. However, some studies have reported contrasting findings [70,71]. This study observed that the consumption of cakes with added chia and flaxseeds increased the feeling of satiety compared to the standard cake. Additionally, flaxseed consumption was associated with a greater sense of satiety when compared to chia seeds. These results are consistent with the findings of studies conducted by Vuksan et al. [66] and Ibrugger et al. [67], further supporting the positive impact of soluble fibers on satiety.

Limitations

This study possesses several strengths. Firstly, the cakes incorporating chia and flax seeds were produced through both laboratory and clinical stages, ensuring robustness in the experimental process. Moreover, the study design allowed individuals to control their variables, thereby minimizing variability. Despite these strengths, certain limitations should be acknowledged. Firstly, all participants were young and healthy individuals, thus limiting the generalizability of the study’s findings to older, obese, and chronically ill populations. Furthermore, the absence of a long-term intervention and the lack of monitoring of individuals’ plasma antioxidant levels restrict the study’s overall impact. Considering the results obtained from this short-term intervention study, future research should encompass diverse populations with varying initial glucose levels and BMI values. Additionally, studies with larger sample sizes and longer intervention periods are required to yield more significant outcomes regarding improved glycemic control, reduced food intake, and effective weight management.

Conclusions

This study demonstrates the efficacy of both chia and flax seeds in terms of glycemic control, increased satiety, and reduced hunger, primarily attributed to their soluble fiber content. Furthermore, the findings indicate that flaxseed exhibits a stronger effect compared to chia in these regards. Additionally, although these seeds do not significantly impact insulin responses, they do diminish cravings for sugary, salty, fatty, and indulgent foods. Based on these results, it is suggested that incorporating foods rich in soluble fiber, such as chia and flax seeds, into our consumption habits through healthy and safe products may have a protective role against obesity and its associated complications and potentially prevent its progression.

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References

1. Green M, Arora K, Prakash S. Microbial medicine: prebiotic and probiotic functional foods to target obesity and metabolic syndrome. Int J Mol Sci. 2020;21(8):2890. doi: 10.3390/ijms21082890.
2. Mohd Ali N, Yeap SK, Ho WY, Beh BK, Tan SW, Tan SG. The Promising future of chia, Salvia hispanica L. J Biomed Biotechnol. 2012;2012:171956. doi: 10.1155/2012/171956 .
3. Carraro JCC, Dantas MS, Espeschit ACR, Martino HSD, Ribeiro SMR. Flaxseed and human health: reviewing benefits and adverse effects. Food Reviews International. 2012;28(2):203-30. doi: 10.1080/87559129.2011.595025.
4. Unites States Department of Agriculture Research Service. USDA Food Composition Databese. [Cited 2022/5/8]; Available from: https://fdc.nal.usda.gov/
5. Ramcharitar A, Badrie N, Mattfeldt-Beman M, Matsuo H, Ridley C. Consumer acceptability of muffins with flaxseed (Linum usitatissimum). Journal of Food Science. 2005;70(7):504-7. doi: 10.1111/j.1365-2621.2005.tb11499.x.
6. Rashed MM, Shallan M, Mohamed D, Fouda K, Hanna L. Biological evaluation of anti-androgenic effect of some plant foods. J Food Nutr Res. 2014;2(9):645-51. doi: 10.12691/jfnr-2-9-19.
7. Malkki Y. Physical properties of dietary fiber as keys to physiological functions. Cereal Foods World. 2001;46(5):196-9.
8. Klotzbach-Shimomura K. Functional foods: The role of physiologically active compounds in relation to disease. Topics in Clinical Nutrition. 2001;16(2):68-78.
9. Marcinek K, Krejpcio Z. Chia seeds (Salvia hispanica): health promoting properties and therapeutic applications – a review. Rocz Panstw Zakl Hig. 2017;68(2):123-9.
10. Pan A, Yu D, Demark-Wahnefried W, Franco O, Lin X. Meta-analysis of the effects of flaxseed interventions on blood lipids. Am J Clin Nutr. 2009;90(2):288-97. doi: 10.3945/ajcn.2009.27469.
11. Nieman DC, Cayea EJ, Austin MD, Henson DA, McAnulty SR, Jin F. Chia seed does not promote weight loss or alter disease risk factors in overweight adults. Nutr Res. 2009;29(6):414-8. doi: 10.1016/j.nutres.2009.05.011.
12. Vuksan V, Jenkins AL, Brissette C, Choleva L, Jovanovski E, Gibbs AL, et al. Salba-chia (Salvia hispanica L.) in the treatment of overweight and obese patients with type 2 diabetes: A double-blind randomized controlled trial. Nutr Metab Cardiovasc Dis. 2017;27(2):138-46. doi: 10.1016/j.numecd.2016.11.124.
13. Vuksan V, Choleva L, Jovanovski E, Jenkins AL, Au-Yeung F, Dias AG, et al. Comparison of flax (Linum usitatissimum) and Salba-chia (Salvia hispanica L.) seeds on postprandial glycemia and satiety in healthy individuals: a randomized, controlled, crossover study. Eur J Clin Nutr. 2017;71(2):234-8. doi: 10.1038/ejcn.2016.148.
14. Mani UV, Mani I, Biswas M, Kumar SN. An open-label study on the effect of flax seed powder (Linum usitatissimum) supplementation in the management of diabetes mellitus. J Diet Suppl. 2011;8(3):257-65. doi: 10.3109/19390211.2011.593615.
15. Hutchins AM, Brown BD, Cunnane SC, Domitrovich SG, Adams ER, Bobowiec CE. Daily flaxseed consumption improves glycemic control in obese men and women with pre-diabetes: a randomized study. Nutr Res. 2013;33(5):367-75. doi: 10.1016/j.nutres.2013.02.012.
16. Schmind M. Beslenme Bilgi Sistemi BEBİS 8.2 Paket programı Entwickelt an der Universital Hohenheim, Struttgart, Germany. 2011. Available at:https://www.bebis.com.tr
17. AACC. International Approved Methods of Analysis, American Association of Cereal Chemists (11 th Edition), USA: St. Paul MN; 2010.
18. A.O.A.C. Official methods of analysis (15 th Edition), USA: Arlington VA; 1990.
19. Anonim. T.C. Gıda, Tarım ve Hayvancılık Bakanlığı, Ulusal Gıda Kompozisyonu Veri Tabanı (Türkomp); 2018.
20. A.O.A.C. Official Methods for Analysis, Association of Official Analytical Chemists (17 th Edition), USA: Arlington VA; 2000.
21. A.A.C.C. American Association of Cereal Chemists International, Approved Methods of the AACC the Association (8 th Edition), USA: St. Paul MN; 2000.
22. A.O.A.C Official Method 991.43. Total, soluble and insoluble dietary fiber in foods. In: Official methods of analysis of AOAC international. 16 th Ed. Cunniff P, eds. Gaithersburg, AOAC International Chapter 32; 1999. pp. 7-9.
23. Flint A, Raben A, Blundell JE, Astrup A. Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. Int J Obes Relat Metab Disord. 2000;24(1):38-48. doi: 10.1038/sj.ijo.0801083.
24. Shaikh RP, Gadhe K. Studies on development and quality evaluation of cupcake fortified with flaxseed and chia seed flour. Pharma Innov. 2020;9:214-7.
25. Lipilina E, Ganji V. Incorporation of ground flaxseed into bakery products and its effect on sensory and nutritional characteristics – a pilot study. Journal of Foodservice. 2009;20(1):52-9. doi: 10.1111/j.1748-0159.2008.00124.x.
26. Chelladurai C, Pandey A, Panmand SA, Nikam S. Development of innovative bakery product chia seed enriched cookies. Int J Food Sci Nutr. 2019;4:19-23.
27. Steffoloni E, De La Hera E, Perez G, Gomez M. Effect of chia (Salvia Hispanica L) addition on the quality of gluten-free bread. Journal of Food Quality. 2014;37(5):309-17. doi: 10.1111/jfq.12098.
28. Pohjanheimo T, Hakala M, Tahvonen R, Salminen S, Kallio H. Flaxseed in breadmaking: effects on sensory quality, aging, and composition of bakery products. Journal of Food Science. 2006;71(4):343-8. doi: 10.1111/j.1750-3841.2006.00005.x.
29. Dündar AN, Aydın E, Yıldız E, Parlak O. Effects of chia seed properties and quality characteristics of regular and low-fat crackers. Food Science and Technology. 2021;41:4. doi: 10.1590/fst.26120.
30. Zhu F, Chan C. Effect of chia seed on glycemic response, texture, and sensory properties of Chinese steamed bread. LWT. 2018;98:77-84. doi: 10.1016/J.LWT.2018.08.016.
31. Koca A, Anil M. Effect of flaxseed and wheat flour blends on dough rheology and bread quality. J Sci Food Agric. 2007;87(6):1172-5. doi: 10.1002/jsfa.2739.
32. Merenkova SP, Lukin AA, Klejman DA. Influence of flaxseed flour additives on quality parameters of bakery products. News of institutes of higher education Food Technology. 2016;5;10-3.
33. R Core Team. R: A language and environment for statistical computing. In: Computing. RFfS, editor. Vienna, Austria. 2019. Available at: https://www.R-project.org/
34. Au MMC, Goff H, Kisch J, Coulson A, Wright A. Effects of soy-soluble fiber and flaxseed gum on the glycemic and insulinemic responses to glucose solutions and dairy products in healthy adult males. J Am Coll Nutr. 2013;32(2):98-100. doi: 10.1080/07315724.2013.767579.
35. Pan A, Sun J, Chen Y, et al. Effects of a flaxseed-derived lignan supplement in type 2 diabetic patients: a randomized, double-blind, cross-over trial. PLoS One. 2007;2(11):1148. doi: 10.1371/journal.pone.0001148.
36. Karakas SE, Perroud B, Kind T, Palazoglu M, Fiehn O. Changes in plasma metabolites and glucose homeostasis during omega-3 polyunsaturated fatty acid supplementation in women with polycystic ovary syndrome. BBA Clin. 2016;5:179-85. doi: 10.1016/j.bbacli.2016.04.003.
37. Nettleton JA, Katz R. n-3 long-chain polyunsaturated fatty acids in type 2 diabetes: a review. J Am Diet Assoc. 2005;105(3):428-40. doi: 10.1016/j.jada.2004.11.029.
38. Machado AM, de Paula H, Cardoso LD, Costa NMB. Effects of brown and golden flaxseed on the lipid profile, glycemia, inflammatory biomarkers, blood pressure and body composition in overweight adolescents. Nutrition. 2015;31(1):90-6. doi: 10.1016/j.nut.2014.05.002.
39. Stuglin C, Prasad K. Effect of flaxseed consumption on blood pressure, serum lipids, hemopoietic system and liver and kidney enzymes in healthy humans. J Cardiovasc Pharmacol Ther. 2005;10(1):23-7. doi: 10.1177/107424840501000103.
40. Dahl WJ, Lockert EA, Cammer AL, Whiting SJ. Effects of flax fiber on laxation and glycemic response in healthy volunteers. J Med Food. 2005;8(4):508-11. doi: 10.1089/jmf.2005.8.508.
41. Barre DE, Mizier-Barre KA, Griscti O, Hafez K. High dose flaxseed oil supplementation may affect fasting blood serum glucose management in human type 2 diabetics. J Oleo Sci. 2008;57(5):269-73. doi: 10.5650/jos.57.269.
42. Cornish SM, Chilibeck PD, Paus-Jennsen L, Biem HJ, Khozani T, Senanayake V, et al. A randomized controlled trial of the effects of flaxseed lignan complex on metabolic syndrome composite score and bone mineral in older adults. Appl Physiol Nutr Metab. 2009;34(2):89-98. doi:10.1139/H08-142.
43. Bernacchia R, Preti R, Vinci G. Chemical composition and health benefits of flaxseed. Austin J Nutr Food Sci. 2014;2(8):1045.
44. Coorey R, Tjoe A, Jayasena V. Gelling properties of chia seed and flour. J Food Sci. 2014;79(5):859-66. doi: 10.1111/1750-3841.12444.
45. da Silva BP, Anunciação PC, Matyelka JCDS, Della Lucia CM, Martino HSD, Pinheiro-Sant'Ana HM. Chemical composition of Brazilian chia seeds grown in different places. Food Chemistry. 2017;221:1709-16. doi: 10.1016/j.foodchem.2016.10.115.
46. Morisset AS, Lemieux S, Veilleux A, Bergeron J, John Weisnagel S, Tchernof A. Impact of a lignan-rich diet on adiposity and insulin sensitivity in post-menopausal women. Br J Nutr. 2009;102(2):195-200. doi: 10.1017/s0007114508162092.
47. Clarke ST, Sarfaraz S, Qi X, Ramdath DG, Fougere GC, Ramdath DD. A Review of the Relationship between lentil serving and acute postprandial blood glucose response: effects of dietary fibre, protein and carbohydrates. Nutrients. 2022;14(4);849. doi: 10.3390/nu14040849.
48. Mohammadi-Sartang M, Sohrabi Z, Barati-Boldaji R, Raeisi-Dehkordi H, Mazloom Z. Flaxseed supplementation on glucose control and insulin sensitivity: a systematic review and meta-analysis of 25 randomized, placebo-controlled trials. Nutr Rev. 2018;76(2):125-39. doi: 10.1093/nutrit/nux052.
49. Khalesi S, Irwin C, Schubert M. Flaxseed consumption may reduce blood pressure: a systematic review and meta-analysis of controlled trials. J Nutr. 2015;145(4):758-65. doi: 10.3945/jn.114.205302.
50. Albert BB, Derraik JGB, Brennan CM, Biggs JB, Smith GC, Garg ML, et al. Higher omega-3 index is associated with increased insulin sensitivity and more favourable metabolic profile in middle-aged overweight men. Sci Rep. 2014;4:6697. doi: 10.1038/srep06697.
51. Wien M, Rajaram S, Oda K, Sabaté J. Decreasing the linoleic acid to alpha-linolenic acid diet ratio increases eicosapentaenoic acid in erythrocytes in adults. Lipids. 2010;45(8):683-92. doi: 10.1007/s11745-010-3430-3.
52. Karlsson FHh, Tremaroli V, Nookaew I, Bergström G, Behre CJ, Fagerberg BF, et al. Gut metagenome in European women with normal, impaired and diabetic glucose control. Nature. 2013;498(7452):99-103. doi: 10.1038/nature12198.
53. Kuo SM. The interplay between fiber and the intestinal microbiome in the inflammatory response. Adv Nutr. 2013;4(1):16-28. doi: 10.3945/an.112.003046.
54. Hervik AK, Svihus B. The role of fiber in energy balance. J Nutr Metab. 2019;2019:4983657. doi: 10.1155/2019/4983657.
55. Tremblay A, Bellisle F. Nutrients, satiety, and control of energy intake. Appl Physiol Nutr Metab. 2015;40(10):971-9. doi: 10.1139/apnm-2014-0549.
56. Capuano E. The behavior of dietary fiber in the gastrointestinal tract determines its physiological effect. Crit Rev Food Sci Nutr. 2017;57(16):3543-64. doi: 10.1080/10408398.2016.1180501.
57. Ho IH, Matia-Merino L, Huffman LM. Use of viscous fibres in beverages for appetite control: a review of studies. Int J Food Sci Nutr. 2015;66(5):479-90. doi: 10.3109/09637486.2015.1034252.
58. Sánchez D, Miguel M, Aleixandre A. Dietary fiber, gut peptides, and adipocytokines. J Med Food. 2012;15(3):223-30. doi: 10.1089/jmf.2011.0072.
59. Rahman S, Zhao A, Xiao D, Park E, Edirisinghe I, Burton-Freeman B. A randomized, controlled trial evaluating polydextrose as a fiber in a wet and dry matrix on glycemic control. J Food Sci. 2017;82(10):2471-8. doi: 10.1111/1750-3841.13855.
60. Tarini J, Wolever TM. The fermentable fibre inulin increases postprandial serum short-chain fatty acids and reduces free-fatty acids and ghrelin in healthy subjects. Appl Physiol Nutr Metab. 2010;35(1):9-16. doi: 10.1139/H09-119.
61. Ye Z, Arumugam V, Haugabrooks E, Williamson P, Hendrich S. Soluble dietary fiber (Fibersol-2) decreased hunger and increased satiety hormones in humans when ingested with a meal. Nutr Res. 2015;35(5):393-400. doi: 10.1016/j.nutres.2015.03.004.
62. Lumaga RB, Azzali D, Fogliano V, Scalfi L, Vitaglione P. Sugar and dietary fibre composition influence, by different hormonal response, the satiating capacity of a fruit-based and a β-glucan-enriched beverage. Food Funct. 2012;3(1):67-75. doi: 10.1039/c1fo10065c.
63. Rahat-Rozenbloom S, Fernandes J, Cheng J, Wolever TMS. Acute increases in serum colonic short-chain fatty acids elicited by inulin do not increase GLP-1 or PYY responses but may reduce ghrelin in lean and overweight humans. Eur J Clin Nutr. 2017;71(8):953-8. doi: 10.1038/ejcn.2016.249.
64. Cohen L, Meira J, Cosendey GM, de Souza AF, Mattos F, Carneiro JRI, et al. Evaluation of the influence of whole and defatted flaxseed on satiety, glucose, and leptin levels of women in the late postoperative stage of bariatric surgery. Obes Surg. 2013;23(2):157-66. doi: 10.1007/s11695-012-0733-x.
65. Lafond DW, Greaves KA, Maki KC, Leidy HJ, Romsos DR. Effects of two dietary fibers as part of ready-to-eat cereal (RTEC) breakfasts on perceived appetite and gut hormones in overweight women. Nutrients. 2015;7(2):1245-66. doi: 10.3390/nu7021245.
66. Vuksan V, Jenkins AL, Dias AG, Lee AS, Jovanovski E, Rogovik AL, et al. Reduction in postprandial glucose excursion and prolongation of satiety: possible explanation of the long-term effects of whole grain Salba (Salvia Hispanica L.). Eur J Clin Nutr. 2010;64(4):436-8. doi: 10.1038/ejcn.2009.159.
67. Ibrügger S, Kristensen M, Mikkelsen MS, Astrup A. Flaxseed dietary fiber supplements for suppression of appetite and food intake. Appetite. 2012;58(2):490-5. doi: 10.1016/j.appet.2011.12.024.
68. Reimer RA, Pelletier X, Carabin IG, Lyon M, Gahler R, Parnell JA, et al. Increased plasma PYY levels following supplementation with the functional fiber PolyGlycopleX in healthy adults. Eur J Clin Nutr. 2010;64(10):1186-91. doi:10.1038/ejcn.2010.141.
69. Sandberg JC, Björck IME, Nilsson AC. Effects of whole grain rye, with and without resistant starch type 2 supplementation, on glucose tolerance, gut hormones, inflammation and appetite regulation in an 11-14.5 hour perspective; a randomized controlled study in healthy subjects. Nutr J. 2017;16:25. doi: 10.1186/s12937-017-0246-5.
70. Juvonen KR, Salmenkallio-Marttila M, Lyly M, Liukkonen KH, Lahteenmaki L, Laaksonen DE, et al. Semisolid meal enriched in oat bran decreases plasma glucose and insulin levels, but does not change gastrointestinal peptide responses or short-term appetite in healthy subjects. Nutr Metab Cardiovasc Dis. 2011;21(9):748-56. doi: 10.1016/j.numecd.2010.02.002.
71. Karhunen LJ, Juvonen KR, Flander SM, Liukkonen KH, Lahteenmaki L, Siloaho M, et al. A psyllium fiber-enriched meal strongly attenuates postprandial gastrointestinal peptide release in healthy young adults. J Nutr. 2010;140(4):737-44. doi: 10.3945/jn.109.115436.