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CLINICAL RESEARCH

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

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Abstract
Background Satiety decline is one of the factors that are involved in weight regain in the postoperative period of bariatric surgery. Nutrients such as long-chain *n*-3 polyunsaturated fatty acid and fibers could assist in food intake control by increasing satiety. Flaxseed is a source of these nutrients, and its consumption could help with possible glycemic control and increased satiety. The aim of this study was to evaluate the influence of whole flaxseed and defatted flaxseed on satiety, postprandial blood glucose, and leptin in post-bariatric women.
Methods A single-blind crossover and randomized study was performed with 18 women in the late postoperative of Roux-en-Y gastric bypass (RYGBP). All women received three test meals containing whole flaxseed, defatted flaxseed, and placebo with 1 week of washout. Satiety was evaluated by a Visual Analog Scale during the fasting period; immediately after ingestion; and 60, 120, and 180 min after meals.
Results There was no difference between test meals for the variables of hunger, satisfaction, fullness, and desire to eat. The basal and postprandial glucose and leptin levels did not differ between the test meals. The intake of defatted flaxseed and placebo muffins resulted in reduced postprandial blood glucose. Postprandial leptin was higher than the baseline (p=0.02); however, only defatted flaxseed showed increased postprandial leptin levels (p=0.044).
Conclusions Whole flaxseed and defatted flaxseed did not promote satiety in women in the late postoperative of RYGBP. However, the test meals with a lower fat content increased the serum leptin levels.

Keywords Obesity · Satiety · Flaxseed · Bariatric surgery · Post-bariatric surgery

Introduction

During the past decade, bariatric surgery has become a growing option for the treatment of many individuals with severe obesity. For most of the patients, the outcome after surgery on the size of the weight loss, the durability of the weight maintenance, and improvements with respect to comorbidities and mortality exceeded expectations in relation to conventional treatment with lifestyle changes and pharmacotherapy [1]. However, 20–30 % of these patients have poor outcomes because of organic factors and psychological and social factors, including difficulty in weight loss and recovery of lost weight in the first year after surgery [2–4].

It has been suggested that mechanisms that are related to weight loss after bariatric surgery, beyond caloric restriction, involve the participation of hormones that assist in food intake control, such as leptin, which is synthesized in the adipose tissue and plays an important role in the regulation of energy balance [5–7].

A decrease in satiety is one of the factors that cause the regain of lost body weight because patients begin to ingest more food over a long-term period [8].

Nutrients such as lipids and fibers are also involved in food intake control. Currently, long chain *n*-3 polyunsaturated fatty acids (*n*-3 PUFA) and fibers have been suggested as nutrients that might increase satiety. Flaxseed (*Linum*

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usitatissimum) is rich in lipids, especially *n*-3 PUFA, which corresponds to 57 % of its total fatty acids [9].

Flaxseed is also a food source of fibers, and two thirds of its fiber content are insoluble fibers, represented by cellulose, hemicellulose, and lignin, which together with the soluble fiber might improve glycemic control [10, 11].

As a source of fiber and lipids, flaxseed can be used to assist in a possible increase in satiety with a consequent reduction in energy intake and glycemic control [10, 12, 13].

This study evaluated the influence of a flaxseed meal on satiety, glucose, and leptin levels of women in the late postoperative period of bariatric surgery.

Subjects and Methods

Subjects

Fifty-two adult women who received Roux-en-Y gastric bypass (RYGBP) with a ring in a university hospital in the city of Rio de Janeiro and with the minimum of 2 years of postoperative time (late postoperative period) were invited to participate in a randomized, crossover, single-blind clinical trial to evaluate the acute effect of flaxseed ingestion in satiety and glucose and leptin levels after the ingestion of three test meals.

Exclusion criteria included subjects who suffered from diabetes mellitus, hypertension, cancer, and recent infectious diseases that could alter blood glycemia; subjects who had visual disturbances that prevented the completion of a visual analog scale (VAS); subjects who used drugs that could interfere with glycemia or lipemia, because it was necessary to standardize patients with regular glycemia; and subjects who received any other type of bariatric surgery. Subjects who could not complete the three trials also had to be excluded, resulting in 18 eligible subjects between 30 and 65 years old.

The research was approved by the Research and Ethics Committee of the Clementino Fraga Filho University Hospital (HUCFF), which is situated in the Federal University of Rio de Janeiro (UFRJ). All of the participants provided written informed consent and were guided on how to complete a 3-day food record before the clinical trial and were advised to maintain habitual physical activity and avoid any food that contained flaxseed 1 week before and during the clinical trials.

Study Design

The study design is illustrated in Fig. 1. Three clinical trials were conducted with each patient, with 1-week intervals between each trial. The sequence of test meals (muffins containing whole flaxseed, defatted flaxseed, or placebo) was randomly distributed. After an overnight fasting of at least 12 h, patients presented themselves to the hospital biochemistry laboratory to collect blood to analyze their

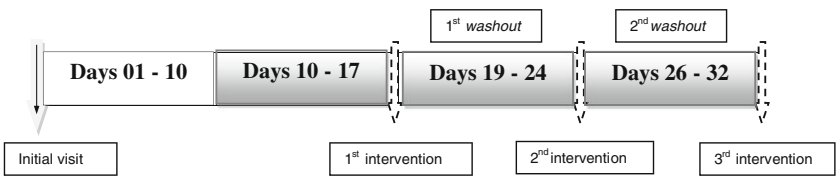

Fig. 1 Study design

Initial visit (written informed consent, anthropometric assessment, orientation with respect to three-day food records, alert to not eat flaxseed during clinical trial)

Intervention: blood collection after overnight fasting (lipemia, glucose and leptin), anthropometric and body composition assessment, three day food record delivery, VAS filling (fasting; immediately after meal intake; and 60, 120, and 180 minutes after meal intake), blood collection 180 minutes after intake (leptin and glucose)

Washout: without flaxseed ingestion.

lipemia, glycemia, and leptin levels. Then, they completed the VAS (T_0) and there was an anthropometric assessment. Subsequently, the patients ingested the test meal within 20 min and completed the VAS immediately after eating and at 60, 120, and 180 min after eating (T_1, T_{60}, T_{120}, and T_{180}, respectively). Finally, we collected blood again for the assessment of postprandial glycemia and leptin levels.

Test Meals

Test meals were prepared by the researchers using whole and defatted flaxseed provided by the Cisbra Group® company (Panambi, RS, Brazil). Muffins weighing 60 g and containing whole flaxseed micronized (M1), defatted flaxseed (M2), or modules of fiber (Fiber Mais®), and protein (Caseical®) with soy oil (placebo—M3) were used. M1 and M2 contained 10 g of flaxseed per muffin. The other ingredients were identical in the three muffins: low-fat yogurt, flour, egg, sugar, sweetener, cinnamon, baking powder, and salt. The whole amount of sugar in each muffin (M1, M2, and M3) was 12 g. The nutritional facts per serving size was obtained by the Brazilian Table of Food Composition [14] and the approximate analysis (per 100 g of muffin) was obtained by the Bromatological Laboratory (Pharmacy School, UFRJ).

Patients received the same volume of no sugar added fruit juice to accompany the muffin, making the meal more appealing. The amount of muffin was the same for each patient. The test meal was calculated individually, according to the resting energy expenditure (REE) of each volunteer using the WHO formula (1985) [15] and corresponding to 1/6 of the REE, comprising 15–25 % of REE in the form of muffins plus juice, which is equivalent to a breakfast energy value.

Usual Dietary Assessment

The patients completed a 3-day food record 1 week before starting clinical trials, giving dietary details during two weekdays and one weekend day. Only one patient did not deliver the food record.

Seventeen food records were analyzed by the DietPro version 5.li Professional® software [16].

Laboratory Assessment

Blood samples were collected in biochemical tubes (BD Vacutainer, Plymouth, UK) from the cubital vein of fasting patients during the morning hours 07:00–07:30. The samples were centrifuged at 4,000 rpm for 10 min. The serum was immediately separated and stored in duplicate at −70 °C in the Nutritional Biochemistry Laboratory of Nutrition Institute Josué de Castro (INJC, UFRJ).

Blood glucose [17] and lipemia (triglycerides, HDL-cholesterol, and total cholesterol) [18, 19] were analyzed by the enzymatic–colorimetric method (commercial kit CELM® and KATAL®) in the Biochemistry Laboratory of the HUCFF, immediately after blood collection. The LDL-cholesterol was calculated according to Friedwald et al. [20].

Quantitative examinations of leptin concentrations were performed in the Nutritional Biochemistry Laboratory of Nutrition Institute Josué de Castro (INJC, UFRJ) by the method of enzyme-linked immuno assay (ELISA Kit, *Linco Research*), and the concentrations according to the producer were expected to be between 0.5 and 100 ng/mL.

Anthropometric and Body Composition Assessment

Body weight (kilograms) was measured on digital scales by Filizola® (capacity of 300 kg and range of 50 g); the individual was barefoot and wearing light clothing. Height (meters) was measured with an anthropometric ruler; the individual was barefoot positioned back to the ruler with heels together. The weight and height were used to calculate the body mass index (BMI = weight/(height)^2) [21]. The measurement of the waist circumference (centimeters) was performed by inelastic anthropometric tape Sanny® according to WHO recommendations [21].

The electrical bioimpedance Byodynamics® model 450 was used for the body composition assessment following a specific protocol [22]. Adiposity was measured by body fat and values of adiposity over 33 % body fat were considered to be excessive [23].

Assessment of Appetite Sensations Associated with Food Intake

We used the Visual Analog Scale, which contains eight questions related to subjective appetite sensations such as hunger, satiety, and desire to eat specific types of food (sweets, snacks, appetizers, and fatty food). The questions were composed of lines of 100 mm with words anchored at each end, describing the extremes (“I have never been more hungry” and “I am not hungry at all”). Subjects were asked to make a mark across the line corresponding to their feelings. Quantification of the measurement was performed by measuring the distance from the left end of the line to the mark [24].

Statistical Analysis

The variables were analyzed as the mean, confidence interval, and minimum and maximum values. The normality of the data distribution was evaluated by the Kolmogorov–Smirnov test. Parametric data concerning a test meal were

analyzed by an ANOVA test with Bonferroni´s post hoc; to compare nonparametric data in the three test meals, we used the Kruskal–Wallis test. To correlate laboratory variables and appetite sensations, we used the Spearman Correlation. The other variables were analyzed using the Wilcoxon test (nonparametric).

The significance level was $p<0.05$, and the statistical analysis program used was SPSS version 16 (SPSS Inc. Chicago, IL, USA).

Results

Subjects

In the present study, the 18 patients had approximately 3.8 (3.1–4.5)years of RYGBP postoperatively. A total of 77 % of the sample ($n=14$) regained weight, and this regain was approximately 10.1 % (5.4–14.7) of the weight excess. The patients are class I obese and present a very increased risk of metabolic complications because of a strong central adiposity, although we did not observe glycemic and lipemic alterations in the sample (Table 1).

Comparing the 3-day food record to the Obesity Latin American Consensus [23], it was observed that the usual dietary intake was low in carbohydrate (52.7 % (48–57.4)), normal in protein (18.9 % (15.5–22.5)), and above the recommended amount of lipid (29.6 % (25.9–33.3)), with a reduced consumption of monounsaturated fatty acids (MUFA) and PUFA, high saturated fatty acids (SFA), and low dietary fiber intake (Table 2).

Test Meal Consumption

The average offer in each of the three meals was 125.5±17.5 g of muffins and 200 ml of no sugar added fruit juice. However, because of the lower gastric capacity, some patients did not ingest all of the volume supplied and the ingested volume was maintained in all of the subsequent tests for the same patient by verifying the rest–intake of the first trial. The average of the muffins and fruit juice intake in each test meal was 99.4±2.4 g and 188.8±3.17 ml, respectively.

Total energy intake of test meals did not differ between M1, M2, and M3. After the test meal intakes, patients who consumed M3 had a higher intake of protein and fiber compared with M1 and M2 intake, and the fiber was higher in M2 consumption compared with M1. The lipid and *n*-3 PUFA consumption was higher in M1 when compared to M2 and M3; when consuming M1 and M2 patient's ingestion amounts of *n*-3 PUFA were above the recommended amount of 1.1 g/day of linolenic acid according to the Food and Nutrition Board [25]. M3 provided a larger amount of lipid compared to M2, while M2 presented the highest content of *n*-3 PUFA compared to M3. The amount of carbohydrate was higher in M2 consumption than in M1, with no difference between both and M3. The higher content of carbohydrate in M2 was because of the lower lipid content of the defatted flaxseed (Table 3).

Table 1 Volunteers' anthropometric (actual, pre-, and postoperative) and biochemical characteristics (minimum, maximum, and mean (CI 95 %)) ($n=18$)

Characteristics	Minimum	Maximum	Mean (CI 95 %)
Age (years)	36	67	48.3 (45.1–50.9)
Time performed RYGBP (years)	2	7	3.8 (3.1–4.5)
Preoperative BMI (kg/m^2)	34	80	50.6 (45.5–55.6)
Actual BMI (kg/m^2)	25.2	45.7	32.9 (31.6–34.1)
Lower BMI reached (kg/m^2)	25	36	30.1 (28.2–31.9)
Weight regained (kg)	0	23	6.0 (2.9–9.1)
Excess weight loss (%)	34	98	71.4 (64.3–78.5)
Recover of excess weight (%)	0	28	10.1 (5.4–14.7)
Actual waist circumference (cm)	81	119	95.0 (92.2–97.9)
Actual lean body mass (%)	49.1	71.3	61.9 (60.4–63.4)
Actual fat body mass (%)	28.6	51.2	37.8 (36.3–39.4)
Actual total body water (L)	29.8	50.0	37.5 (36.0–38.9)
Actual basal metabolic rate (kcal/day)	1,260.0	2,056.0	1,606 (1,543–1,669)
Total cholesterol (mg/dL)	119.0	223.0	158.9 (152.2–165.6)
HDL-c (mg/dL)	47.0	112.0	64.0 (59.7–68.4)
LDL-c (mg/dL)	29.0	140.0	79.7 (73.4–85.9)
Triglycerides (mg/dL)	33.0	157.0	74.1 (66.1–82.1)
Glucose (mg/dL)	61.0	121.0	79.9 (76.7–83.0)
Leptin (ng/mL)	2.6	59.2	16.8 (13.7–19.9)

BMI body mass index, *LDL-c* low-density lipoprotein cholesterol, *HDL-c* high-density lipoprotein cholesterol, *CI* confidence interval

Table 2 Volunteers' habitual dietary intake (minimum, maximum, and mean (CI 95 %)) (n=17)

Variables	Minimum	Maximum	Mean (CI 95 %)
Total energy intake (kcal/day)	604.9	2,476.1	1,277.2 (1,031.1–1,523.3)
Carbohydrate (% TEI)	31.3	68.2	52.7 (48.0–57.4)
Protein (%TEI)	10.5	36.5	18.9 (15.5–22.5)
(g/kg of BW/day)	0.3	1.6	0.7 (0.5–0.8)
Fat (%TEI)	16.6	43.9	29.6 (25.9–33.3)
MUFA (% TEI)	5.3	34.9	9.2 (7.2–13.9)
PUFA (%TEI)	2.2	10.7	4.5 (3.3–5.7)
SFA (%TEI)	5.1	14.0	10.0 (8.9–11.1)
Fiber (g/day)	9.2	26.4	15.6 (13.0–18.3)

TEI total energy intake, *BW* body weight, *MUFA* monounsaturated fatty acid, *PUFA* polyunsaturated fatty acid, *SFA* saturated fatty acid, *CI* confidence interval

Appetite Sensation, Blood Glucose, and Leptin Levels

There was no difference between the test meals with respect to the variables of hunger, satiety, fullness, and desire to eat from the values found in the VAS analysis (Table 4). The appetite sensation behavior M1, M2, and M3 during the postprandial time also did not differ (p>0.05; Fig. 2).

The fasting and postprandial blood glucose and leptin levels did not differ between the M1, M2, and M3. In the consumption of M1, there was no change in the postprandial blood glucose; however, in M2 and M3, the postprandial blood glucose was reduced (p=0.038 and p=0.020, respectively; Table 5). Postprandial leptin levels were higher than the baseline (p=0.02) in the sample, but when evaluating this hormone separately, only intake of M2 presented a leptin level increase in the postprandial time (p=0.044).

There was a moderate negative correlation between the blood glucose and postprandial hunger (r=−0.46 and p=0.06) in M1 intake. In M2 and M3, there was no correlation (r=0.14 and p=0.57, r=−0.11 and p=0.65, respectively) between these variables. Leptin did not correlate with the sensations of appetite in the baseline and postprandial times, and there was no relationship of leptin with the baseline and postprandial glucose.

Discussion

To date, this research is the first clinical study to evaluate the influence of flaxseed, a rich source of fiber and fat, on the satiety of women in the late postoperative period of RYGBP and to suggest an alternative diet that could help in food intake control, avoiding lost weight regain after surgery.

In this study, 77 % of the patients regained the excess lost weight, which is also verified by Magro et al. [4] in a prospective study of 782 patients undergoing bariatric surgery, in which 50 % of the samples have regained the lost weight 24 months after surgery.

In spite of the recovery of weight and the usual high-fat diet, our sample showed appropriate lipemia and glycemia. The regulation of these metabolic parameters can be observed after performing the RYGBP [26].

Table 3 Test meals energy and nutrient composition (mean (CI 95 %)) (n=18)

	M1 (whole flaxseed)	M2 (defatted flaxseed)	M3 (placebo)	p value[a]
TEI (kcal)	289.8 (256.8–322.7)	313.1 (277.2–348.9)	317.7 (284.4–351.1)	0.43
Protein (g)	8.4 (7.4–9.5)[b]	8.6 (7.6–9.7)[d]	10.8 (9.6–12.1)	0.004
(%)	11.6 (11.3–11.8)	11.00 (10.8–11.2)	13.6 (13.35–13.81)	
Fat (g)	3.7 (3.3–4.2)[b,c]	1.2 (1.0–1.3)[d]	2.7 (2.4–3.0)	<0.001
(%)	11.6 (11.3–11.8)	3.4 (3.3–3.5)	7.7 (7.6–7.8)	
Carbohydrate (g)	55.1 (49.0–61.3)[b]	66.5 (58.9–74.1)	62.0 (55.6–68.4)	0.047
(%)	76.2 (75.8–76.6)	85.1 (84.8–85.2)	78.2 (77.9–78.5)	
Fiber (g)	5.5 (4.9–6.1)[b,c]	7.0 (6.2–7.8)[d]	10.1 (9.0–11.1)	<0.001
n-3 PUFA (g)	3.0 (2.6–3.4)[b,c]	1.6 (1.4–1.8)[d]	0.3 (0.2–0.3)	<0.001

TEI total energy intake, *n-3 PUFA* long chain n-3 polyunsaturated fatty acid, *M1* whole flaxseed, *M2* defatted flaxseed, *M3* placebo

[a] The differences between test meals were analyzed by ANOVA with Bonferroni's post hoc for a 5 % probability

[b] M1 vs. M2

[c] M1 vs. M3

[d] M2 vs. M3

Table 4 Comparison of appetite sensations in baseline and postprandial related to the test meal intake (minimum, maximum, and mean (CI 95 %)) (n=18)

Test meal		Minimum	Maximum	Mean (CI 95 %)	p value[a]
Baseline hunger	M1	0.4	9.5	5.2 (3.7–6.6)	0.928
	M2	1.4	10	5.5 (4.1–6.8)	
	M3	0	10	5.5 (3.9–6.9)	
Baseline satisfaction	M1	0	5.7	2.5 (1.5–3.4)	0.846
	M2	0	8.1	2.9 (1.6–4.3)	
	M3	0	10	2.8 (1.5–4.2)	
Baseline fullness	M1	0	6	1.9 (0.8–3.0)	0.321
	M2	0	10	2.6 (1.2–3.9)	
	M3	0	6.5	1.4 (0.5–2.4)	
Baseline desire to eat	M1	1.7	9.5	5.6 (4.6–6.7)	0.654
	M2	0	9.8	5.8 (4.6–7.1)	
	M3	3	10	6.3 (5.3–7.3)	
Postprandial hunger	M1	0	9.3	4.8 (3.4–6.3)	0.607
	M2	0.5	9.3	5.7 (4.5–6.9)	
	M3	0	9.1	5.1 (3.7–6.5)	
Postprandial satisfaction	M1	0.6	9.2	4.4 (3.1–5.7)	0.894
	M2	0	8.2	3.9 (2.8–5.1)	
	M3	0.5	10	4.1 (2.6–5.6)	
Postprandial fullness	M1	0.5	9.2	4.4 (3.2–5.6)	0.871
	M2	0.3	8.8	4.1 (2.6–5.5)	
	M3	0.5	10	3.9 (2.5–5.4)	
Postprandial desire to eat	M1	2.0	9.9	5.7 (4.6–6.8)	0.690
	M2	3.7	9.8	6.3 (5.4–7.2)	
	M3	0	9.5	5.9 (4.9–7.1)	

[a]The differences between the test meals were analyzed by ANOVA for the 5 % probability

M1 whole flaxseed, *M2* defatted flaxseed, *M3* placebo

The usual intake of protein per kilogram of body weight is 0.73 (0.5–0.8)g/kg, which can imply a low-protein diet, but the percentage of total energy intake, 18.9 (15.5–22.5)%, features a normal protein diet [23, 27] because it is still an obese population. It was also verified that the fiber intake was below the recommendation of 20–30 g per day [23]. Inadequate fiber intake is one of the factors that can hinder weight loss because of its action in providing increased satiety [27]. A Brazilian study with 48 patients, who were followed pre- and postoperatively, showed a decrease in the fiber intake from 15.9 g/day to 9.7 g/day after 12 months postoperatively.

The need to select and appropriately chew the food involves the most needed actions and requires the

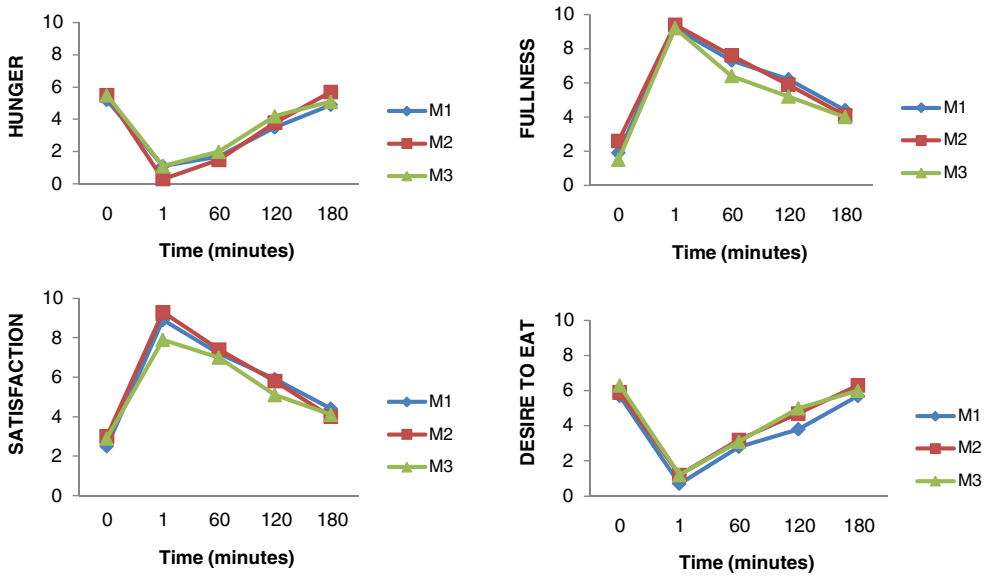

Fig. 2 Appetite sensation behavior for each test meal (*M1*. *M2*, and *M3*) during the postprandial time period

Table 5 Comparison of blood glucose and leptin levels between test meals for the baseline and postprandial times (mean (CI 95 %)) (n=16)

Variables	M1 mean (CI 95 %)	M2 mean (CI 95 %)	M3 mean (CI 95 %)	p value[a]
Baseline glucose (mg/dl)	75.1 (68.9–78.6)	81.3 (72–80.9)	76.5 (68–76.6)	0.15
Postprandial glucose (mg/dl)	73.8 (71.6–78.6)	76.5 (77.9–84.6)	72.3 (73.5–79.4)	0.29
p value[b]	0.228	*0.038*	*0.020*	
Baseline leptin (ng/ml)	19.09 (12.0–26.2)	16.49 (12.6–20.4)	15.02 (9.3–20.7)	0.41
Postprandial leptin (ng/ml)	22.06 (13.6–30.5)	22.9 (14.5–31.3)	19.0 (9.5–28.5)	0.57
p value[b]	0.098	*0.044*	0.796	

[a] The differences between the test meals were analyzed by the Kruskal–Wallis test for 5 %

[b] The differences between the baseline and postprandial times per test meal were analyzed by the Wilcoxon for a 5 % probability

M1 whole flaxseed, *M2* defatted flaxseed, *M3* placebo

availability of more time for each meal. Furthermore, inappropriate chewing, which is characteristic of these patients, generates difficulty in passing certain foods such as meat and fiber, by the anastomosis surgery or ring, which could lead to a reduced intake of those foods and a preference for liquids [28].

Some authors suggest that there is a low adherence to the recommended diet postoperatively, and the energy intake increases significantly during the postoperative time [29, 30]. Brolin et al. [29] found that, prior to the surgery, the patient's ingested 2,604±1,087 kcal/day, with 18 % of protein, 46 % of carbohydrate and 36 % of fat. At 6 months postoperatively, the patients consumed 890±407 kcal/day, and the proportion of macronutrients was similar to the preoperative time. At 2.5 years postoperatively, the energy intake increased to 1,386±578 kcal/day, and the macronutrient distribution remained similar to the previous period. This augment in energy intake contributes to the weight regain, which usually occurs in the second year after surgery [30]. To equal the amount of flaxseed (10 g) used in the test muffins (M1 and M2), some changes in the test meal composition were made, considering the difference in the composition of the whole and defatted flaxseed, which resulted in differences in macronutrients between them. The energy value did not differ between the muffins.

As shown in Table 3, M1 presented a higher fat content than the other test meals; however, there was no difference between the test meals for the variables hunger, satisfaction, fullness, and desire to eat in the postprandial time. With respect to lipids, it is known that the degree of unsaturation, chain length, position, and double-bond configuration could influence the postprandial lipid metabolism [31].

In a long-term study, Kratz et al. [32] tested the hypothesis that n-3 PUFA lower body weight and fat mass by reducing appetite and/or by increasing energy expenditure. They studied 26 subjects who were overweight and obese and who received a diet that was high in n-3 PUFA (EPA and DHA) from vegetable and animal sources and a control diet (isocaloric) for 2 weeks, followed by 12 weeks of diet ad libitum. They concluded that n-3 PUFA had no effect on the appetite, energy intake, resting energy expenditure, fat mass, or body weight of the subjects.

Casas-Agustench et al. [33] studied the acute effect of lipids on satiety in 29 healthy adults who ingested three isocaloric diets prepared with almonds (high in PUFA), olive oil (source of monounsaturated fatty acids—MUFA), or milk products (high in saturated fatty acids—SFA). The VAS was applied during fasting and 30, 90, 120, and 300 min after food intake. Similarly, Strik et al. [34] also assessed the degree of fat saturation on satiety in 18 healthy men. Both studies verified that the quality of the lipids had no effect on the satiety, a result that confirms what we found in the present study.

On the other hand, Lawton et al. [35] found that PUFA tended to promote greater satiety compared to SFA and MUFA in an acute test with 20 healthy subjects of both genders consuming three types of diets that were rich in SFA, PUFA, and MUFA.

In a crossover study, Burton-Freeman et al. [36] evaluated, in three groups of healthy subjects, the satiety effect of three test meals containing 30 % of their total energy from lipids found in fresh almonds, almond oil incorporated into muffins, and a mixture of safflower and corn oils, also incorporated into muffins (control group). Compared to men, women showed greater satiety after eating muffins containing almond oil (high MUFA and PUFA) compared to fresh almonds.

As discussed by Casas-Agustench et al. [33], the source and amount of lipids are possibly more important in the satiety effect than the type of lipid. In our study, we analyzed the effect of 3.7 g of lipids from flaxseed muffin, while Lawton et al. [35] found a positive result with test meals that contained 80 g of lipids.

When fiber is evaluated for its satiety effect, it is observed that the fiber viscosity function in the physiological response in the appetite control is not fully established, in spite of the fact that there is a discussion about the increase in satiety and fullness feelings with unique doses of viscous

fiber compared to controls with low fiber [37, 38]. In contrast, in our study, consumption of M3 showed a greater fiber intake (10.1 g) compared to M1 and M2 but did not significantly influence any of the appetite sensations.

Touyarou et al. [39] evaluated the consumption of five breads with different amounts of fiber (high and low content) on the satiety of 32 healthy subjects of both genders. At 150 min after the test meal intake, the authors did not observe any influence on the postprandial appetite sensations. Similarly, Willis et al. [40], in a double-blind, crossover, randomized study with healthy subjects, did not observe differences in satiety, gut hormones (ghrelin, GLP-I, and PYY), and food intake after 180 min following the consumption of muffins with 0, 4, 8, and 12 g of a soluble fiber mixture at breakfast.

Levine et al. [41] showed the opposite result, that the amount of fiber intake can influence the postprandial sensation of appetite, by observing an inverse linear correlation between the amount of fiber intake and the energy consumed in the next meal.

The difference between the studies that found increased satiety with meals rich in fiber and the present study could be related to the type of fiber that was used. A breakfast that is high in insoluble fiber could have a higher ability to reduce subsequent food intake when compared to a breakfast that is rich in soluble fiber [39].

Others factors can also influence satiety, such as palatability, meal volume, nature and form or presentation, as well as the caloric content and macronutrient intake, the degree of knowledge about the food that is consumed, the interaction of the effects of diet with the eating habits of people in the study, and the subjects characteristics (age, sex, food restriction, and body composition) [31].

Furthermore, accelerated gastric emptying and reduced gastric distension could predispose healthy subjects to overeating. However, in addition to gastric distension, the presence of nutrients in the small intestine is critical for satisfaction and satiety. After bariatric surgery, there is a rapid transit of nutrients to the jejunum, which stimulates certain anorexigenic hormones [42, 43].

The efficiency of intestinal absorption, determined by factors such as the viscosity and structure of the meal, can also influence the release of gut peptides. A liquid meal, for example, in spite of rapid emptying, can be completely absorbed in the duodenum and not reach the bottom of the ileum in healthy subjects; consequently, it does not stimulate the L cells (located in the distal intestine and activated in response to the presence of carbohydrates and fat) [42, 44], this fact possibly does not occur in bariatric patients.

The baseline and postprandial glucose and leptin levels did not differ between test meals, and only M2 intake showed a decrease in glucose and an increase in leptin in the postprandial time periods.

Some authors state that the ingestion of a meal does not acutely regulate serum leptin levels because it follows an oscillatory pattern that is related to the circadian rhythm; in other words, although leptin is a potent anorexigenic hormone, it cannot be considered to be a short-term regulator because it does not promote a change in the total intake during a meal [45, 46]. The peak of the leptin response to the food consumption occurs only a few hours (4–7 h) after the end of meal intake, but because it is regulated by the caloric intake, the leptin plasma levels, and their action potential are associated with diet macronutrient content, especially lipids [12, 47]. Moreover, leptin is also produced in the stomach and is secreted in response to food intake; thus, it is speculated that leptin could be involved in the acute regulation of food intake, working as a satiety hormone [48–50].

Ainslie et al. [51] performed a study with two groups of rats that were fed a high-fat diet (36 % fat as soybean oil) and a low-fat (3 % fat) diet. After 4 weeks of the diet, the authors verified that, after 12 h of fasting, the plasma leptin levels were 24 % lower in the high-fat diet group than the low-fat group, concluding that the decrease in leptin secretion could contribute to body weight gain. The authors suggest that the high-fat diet affects the reduction of insulin activity in the glucose uptake in adipocytes, which can be associated with a reduced expression and secretion of leptin in these cells. Additionally, they found an association between an increase in lipolysis and a decrease in leptin synthesis, which explains the decreased synthesis of this hormone after a high-fat diet. These results could explain the fact that M2, the muffin with the lower fat intake, had a larger variation in the leptin levels at the baseline and postprandial times.

In obese subjects who underwent RYGBP, plasma leptin levels have been observed to decrease depending on the absorptive and restrictive features that are inherent to the surgery; therefore, strategies that result in an increased secretion of this hormone can contribute to appetite control and body weight maintenance in the long-term [52].

The effect of dietary fat on leptin levels could be dependent on the fat type, considering that the different sources of fat have different effects on the lipolysis and glucose uptake by adipose tissue [51, 53, 54].

A study developed during 16 weeks with 26 obese and overweight subjects tested the hypothesis that a diet rich in *n*-3 PUFA (3.6 % VET) from plant sources (safflower oil) and from animal sources (fish oil) would reduce body weight by decreasing the appetite or increasing the energy expenditure. It was found that *n*-3 PUFA did not influence the plasma leptin levels and the body weight; therefore, it had no role in regulating the food intake and energy expenditure [32], as observed in the present study, because M1 provided a higher intake of this type of lipid without changes in the postprandial leptin levels.

The postprandial glucose decrease after M2 and M3 intake could be a result of the postprandial increase in plasma insulin after a meal with a higher content of carbohydrates and a meal with a higher content of fiber, respectively. With respect to the plasma glucose reduction after M2 intake, it is known that postprandial glucose depends on the relation between the secretion of glucagon and insulin and the amount and type of carbohydrates ingested. The glycemic peak depends on the amount of carbohydrates, the type and the meal composition and also on the time of the day that the meal is eaten; after breakfast, this peak is greater than at other points of the day. The blood glucose begins to rise 10 min after food intake and reaches its maximum value at 60 min; however, in nondiabetic subjects, in 2–3 h (180 min) after carbohydrate intake, the blood glucose levels are closer to baseline levels [55]. Depending on the carbohydrate intake, insulin secretion can influence the elevation of postprandial leptin levels [56], which could explain the decrease in the blood glucose and the increase in the leptin levels observed in M2 intake after 180 min.

Krog-Mikkelsen et al. [57] tested two meals with a high and low glycemic index in overweight women over 10 weeks and observed lower levels of plasma glucose and serum insulin and increased fullness after the low glycemic index meals, while the serum leptin levels did not change between the groups. It is possible that M3 showed a reduction in the postprandial blood glucose because of its soluble fiber content [13].

The present study showed some limitations, such as the possibility of non-standardization of the RYGBP surgery; the gastric pouch could be different among bariatric patients from our sample. However, a crossover study minimizes this problem because all of the patients were enrolled in all of the three test meals. Another limitation is that the muffins were not sensory analyzed, which would discard the possible differences in the palatability of the meal, although there were not any rejection reports about the taste of the test meals. The third limitation refers to the amount of fat that was tested; however, large amounts of fat are not recommended.

Research that assesses the influence of macronutrients and fibers, as well as research that investigates the effect of certain foods on food intake and, consequently, on weight loss and weight maintenance, still have contradictory results because of the heterogeneity of the studies, such as the difference in experimental design; the characteristics of the studied populations such as gender, ethnicity, nutritional status, and level of physical activity; the type and amount of nutrient or food assessed; the type of control group; and the intervention time.

Conclusions

In obese women in postoperative RYGBP, whole and defatted flaxseed did not promote satiety. However, the reduction of fat in one of the test meals increased the serum leptin levels.

To our knowledge, our study addresses unique aspects in this specific population, which makes it difficult to compare results. Considering the subjective nature of the visual analog scales that are used to assess appetite, we believe that other hormonal assessments are needed to clarify and provide more support for the arguments made in this study.

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Conflict of interest The authors declare that they have no conflicts of interest.

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