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Addition of dietary fiber sources to shakes reduces postprandial glycemia and alters food intake

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Abstract

Introduction: **Obesity and Type 2 diabetes may be controlled by foods capable of modulating food intake and blood glucose.**

Objectives**: We investigated whether the addition of food sources of fiber or phaseolamin to shakes can control food intake and reduce postprandial glycemia.**

Methods**: This was a randomized, single blind, crossover design study (food intake: n=22; glycemia: n=10). Five liquid meals presenting similar amounts of macronutrients (C - control shake, OB - oat bran shake, F - flaxseed shake, WB - white bean extract shake, and UB - unripe banana flour shake) were consumed in five non-consecutive days. Participants kept dietary records during the subsequent 24 hours. Blood glucose was measured at 0 (immediately before), 15, 30, 45, 60, 90 and 120 minutes after the ingestion of each shake and the incremental areas under the curves (iAUC) were calculated.**

Results**: Compared to C, there was a significant increase in fiber intake after the consumption of OB (+17.9g), F (+19.1g), and UB (+12.6g), and in fat after the consumption of OB (+25,4g). There was a non-significant reduction of daily energy intake in F compared to C (1524kJ; P=0.10). There was a 43% reduction in the iAUC (P=0.03) in response to UB consumption.**

Conclusions**: Unripe banana flour reduced postprandial glycemic response of shakes almost by half. The effect of oat bran and flaxseed on food intake needs further investigation in long-term studies.**

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LA ADICIÓN DE FUENTES DE FIBRA DIETÉTICA A BATIDOS REDUCE LA GLUCEMIA POSPRANDIAL Y ALTERA LA INGESTA DE ALIMENTOS

Resumen

Introducción: **Obesidad y diabetes de tipo 2 pueden ser controlados por alimentos capaces de modular la ingesta de alimentos y la glucemia.**

Objetivos**: Se investigó si la adición de alimentos fuentes de fibra o fasolamina a batidos puede controlar la ingesta de alimentos y reducir la glucemia posprandial.**

Métodos**: Estudio aleatorizado, simple ciego, de diseño cruzado (ingesta de alimentos:n=22; glucemia:n=10). Cinco batidos con cantidades similares de macronutrientes (C - control batido, SA - salvado de avena batido, L - linaza batido, FB - extracto de frijol blanco batido y PI - harina de plátano no maduro batido) fueron consumidos en cinco días no consecutivos. Las participantes registraron la ingesta de alimentos en las 24 horas subsiguientes. La glucosa en sangre se midió a 0 (inmediatamente antes), 15, 30, 45, 60, 90 y 120 minutos después de la ingestión de cada batido y se calcularon las áreas incrementales bajo las curvas (AIBC).**

Resultados**: En comparación a C, hubo un aumento significativo en la ingesta de fibra después de que el consumo de SA(+17,9g), SL(+19,1g), y PI(+12,6g), y en la grasa después del consumo de SA(+25,4g). Se encontró una reducción no significativa de la ingesta diaria de energía en L (1524kJ, P=0,10) en comparación con C. Hubo una reducción del 43% en el AIBC (P=0,03) en respuesta al consumo PI.**

Conclusiones**: Harina de plátano no maduro reduce la respuesta glucémica posprandial de batidos casi a la mitad. El efecto de salvado de avena y linaza en la ingesta de alimentos requiere mayor investigación en estudios a largo plazo.**

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Palabras clave: *Glucemia. Fibra Dietética. Ingestión de Energía. α-Amilase.*

Abbreviations

BMI: Body mass index.
CCK: Cholecystokinin.
C: Control shake.
F: Flaxseed shake.
GLP-1: Glucagon-like peptide-1.
IAUC: Incremental areas under the curves.
OB: Oat bran shake.
UB: Unripe banana flour shake.
WB: White bean extract shake.
WHO: World Health Organization.

Introduction

Obesity and type 2 diabetes are closely related diseases. About 80% of the individuals with type 2 diabetes are overweight or obese[1]. According to the World Health Organization (WHO), obesity prevalence among adults has more than doubled between 1980 and 2008[2]. Diabetes worldwide estimated prevalence should increases from 285 million in 2010 (6.4%) to 439 million in 2030 (7.7%)[3]. Since excessive body weight has such an important role in the onset of diabetes, there is an urgent need to develop and implement nutrition strategies to prevent, ameliorate and manage these problems[4]. One important strategy is the inclusion of certain kinds of foods capable of reducing postprandial glycemia and controlling food intake. Adding high dietary fiber foods such as oat bran, flaxseeds, and unripe banana flour, or adding a food source of a natural blocker of α-amylase such as white bean extract to high carbohydrate meals may be useful in that matter.

Resistant starch is also a type of dietary fiber. Its effect on food intake and glycemic response needs further investigation[5]. One of the most important sources of natural resistant starch is unripe banana. The content of resistant starch of unripe banana is affected by processing and storage conditions[5]. Due to that, Brazilian's researchers developed the unripe banana flour, a more stable product that maintains the content of resistant starch of unripe banana[6]. To our knowledge there has not been published any human study, which assessed the effect of the ingestion of unripe banana flour added to liquid meals on postprandial glycemia and food intake.

White bean extract appears to be a novel and potentially effective food for reducing the postprandial glycemic response of a meal[7]. That extract contains high levels of phaseolamin, an α-amylase inhibitor, which has been called 'starch-blocker'. Soluble fibers may enhance viscosity of meals, reduce the rate of starch digestion, alter the rate of glucose absorption, and reduce food intake by increasing satiety[8,9]. Besides its nutritional benefits, soluble fibers are commonly used in the food industry to modify viscous properties of liquid and semi-liquid food products and meals[8]. Oat bran and flaxseeds are important sources of soluble fibers. However, the acute impact of its consumption on postprandial glycemia and food intake remains poorly explored and the results of few studies published so far are inconsistent[10-12]. Because of that, it might be able to reduce the glycemic response when added to high-carbohydrate meals[13]. The influence of insulin on food intake regulation has been known for a long time and the reduction of insulin secretion by blocking carbohydrate digestion may reduce food ingestion[14].

Objectives

The present study assessed the impact of the addition of three dietary fiber sources (oat bran, flaxseed, and unripe banana flour) and one of phaseolamin (white bean extract) to shakes compared to a control shake on food intake and postprandial glycemia in healthy subjects.

Methods

Subjects

Twenty-two healthy, normal weight (BMI between 18.5 and 25 kg/m^2)[15], normoglycemic (fasting glucose between 3.9 and 5.5 mmol/L)[16], adult (aged 18 to 30 years) subjects participated in this study. The participants were recruited through posters, local radio and newspapers advertisements. All of them were submitted to food intake protocol. Postprandial glycemia was assessed in 10 of these participants. Samples sizes were calculated considering the incremental area under the glycemic response curve (iAUC) and energy intake as the main variables[17]. A statistical power of 90% and an expected difference of 10% in the baseline values were adopted. The following exclusion criteria were considered: smokers, consumption of more than two doses of alcohol (<20mL) per day, pregnant or lactating, type 1 or 2 diabetics or glucose intolerants, family history of type 1 or 2 diabetes, recent changes (less than three months) in diet or physical activities habits, and use of drugs that affect metabolism.

All participants provided written informed consent. The study was approved by the Ethics Committee on Human Research of the Federal University of Viçosa, Brazil, and was conducted in accordance with the Declaration of Helsinki.

Test meals

Five types of liquid meals were tested: control shake (C), oat bran shake (OB), flaxseed shake (F), white bean extract shake (WB) and unripe banana flour shake (UB). The shakes were design to provide 75g of available carbohydrate and equal amounts of ener-

gy, protein and fat, based on nutrition facts labels (Table 1). They presented similar volume, appearance, and texture. Soybean oil was added in order to reach the fat content of F, a shake made with flaxseeds, which have a high-fat content. Chocolate (cocoa) powder was added to all shakes in order to make the taste

Table I
Ingredients and nutritional composition of the shakes

Shakes[a]	*Ingredients*		*Nutritional Composition*				
	Types	*Added amounts*	*Energy (kJ)*	*Protein (g)*	*Fat (g)*	*Available carbohydrate (g)*	*Fiber (g)*
Control	Powdered skim milk	23.7 g	2043.9	10.0	16.5	75.0	2.2
	Cocoa powder	15.0 g					
	Maltodextrin	58.5 g					
	Soybean oil	15.4 g					
	Sweetener	20 drops					
Oat bran	Oat bran	50.0 g	2043.9	10.0	16.5	75.0	12.2
	Powdered skim milk	3.71 g					
	Cocoa powder	15.0g					
	Maltodextrin	41.8 g					
	Soybean oil	12.4 g					
	Sweetener	20 drops					
Flaxseedb	Flaxseed	36.6 g	2043.9	10.0	16.5	75.0	12.2
	Powdered skim milk	4.9 g					
	Cocoa powder	15.0 g					
	Maltodextrin	68.3 g					
	Soybean oil	0.0 g					
	Sweetener	20 drops					
White bean extract	White beans powder	1.0 g	2043.9	10.0	16.5	75.0	2.2
	Powdered skim milk	22.3 g					
	Cocoa powder	15.0 g					
	Maltodextrin	57.6 g					
	Soybean oil	15.4 g					
	Sweetener	20 drops					
Unripe banana flour	Unripe banana powder	45.5 g	2043.9	10.0	16.5	75.0	7.2
	Powdered skim milk	17.5 g					
	Cocoa powder	15.0 g					
	Maltodextrin	31.9 g					
	Soybean oil	13.8 g					
	Sweetener	20 drops					

[a]Water was added to test meals in sufficient quantities to result in a final volume of 300mL. bThe fat content is derived from the oil present in flaxseed.

similar and provided 2.2g of fiber per shake (portion consumed). Control was a virtually fiber free shake. Oat bran and flaxseeds were added to the test meals in sufficient quantities to provide 10g of fibers[18]. Unripe banana flour was added as much as tolerated by the subjects (45.5g, providing 5g of fibers). White bean extract was used in the amount indicated in the pack label (1000mg). The ingredients were obtained from the local market. The test meals were well tolerated.

Experimental protocol

This is a single blind, five non-consecutive days, crossover, Latin square design study. Throughout the screening visits, participants completed health, demographic, and physical activity questionnaires[19], had their height, body weight and body composition measured, and were asked about their habitual dietary habits[20].

In each one of the five experimental sessions, participants reported to the laboratory after a 10–12-hour overnight fast and consumed randomly one of the test meals, within 10 min. The ingredients of each test meal were blended for 5 min and immediately offered to the participants. The test meals were prepared by the research team in the Food Intake Laboratory at Federal University of Viçosa, Brazil. There was a washout period of at least one day between sessions. Participants stayed in the laboratory for the following 120 min for postprandial glycemia assessments. No other food or beverage was allowed during that time. Food intake was assessed after they left the laboratory over the next 24-hours after the test meals consumption. All participants were instructed to maintain their habitual physical activity level during the experiment. Physical activity was assessed during the screening visit and at the end of the tests to verify the protocol compliance[19].

Dietary assessment

Habitual dietary habits were assessed using a semi-quantitative food frequency questionnaire (Table II)[20]. During the test days, food intake was assessed through 24-hours food records. Instructions for filling out these food records were individually given in the first five test days. Each dietary record was reviewed with the participant to ensure accuracy and completeness. Data were analyzed by a single individual using the Avanutri® software package (version 3.1.5, 2009, Avanutri & Nutrição Serviços e Informática Ltda Me, Rio de Janeiro, RJ, Brazil).

Postprandial glycemia

Capillary finger-stick blood samples were taken in the fasting state (0 min) and at 15, 30, 45, 60, 90 and 120 min after the start of the test meal. Glucose levels were measured using a glucometer. The correlation coefficient (r) between the glucometer (One Touch Ultra II®, LifeScan Inc., Milpitas, CA, United States) and the standard laboratory instrument (glucose autoanalyzer YSI Model 2300 STAT, Yellow Springs, OH, United States) was 0,984, and the variations coefficient (CV) was less than 2.1% for blood samples with glucose levels higher than 3.9mmol/L. The incremental area under the glycemic response curve (iAUC) was calculated by the trapezoidal method[21], using the software SlideWrite® (version 7.0, 2010, Advanced Graphics Software, San Diego County, CA, United States).

Table II
Baseline characteristics of the study subjects (mean ± SEM)

	Study Protocol	
	Food Intake (n=22)	*Postprandial Glycemia (n=10)*
Male/female	15/7	5/5
Age (years)	22.12 ±0.31	22.90 ± 0.53
BMI (kg/m²)	22.00 ± 0.46	22.10 ± 0.63
Body fat (%)a	20.42 ± 0.83	20.28 ± 1.50
Glycemia (mmol/L)b	-	5.13 ± 0.07
Energy intake (kJ/d)	8516.00 ± 420.38	8523.68 ± 482.65
Carbohydrate intake (g/d)	282.33 ± 17.35	277.57 ± 19.44
Protein intake (g/d)	74.27 ± 4.77	80.03 ± 8.42
Fat intake (g/d)	67.66 ± 3.58	67.42 ± 4.41
Fiber intake (g/d)	15.82 ± 1.21	17.39 ± 1.58

[a]Measured by skinfold. b Fasting glycemia, mean of five test days.

Statistical analysis

Statistical analyses were carried out with SPSS for Windows (version 17.0, 2008, SPSS Inc.). Data normality and homoscedasticity were assessed by Kolmogorov-Smirnov and Levene tests, respectively, and expressed as mean and standard error of mean (SEM). One-Way ANOVA was used to assess significant differences between dietary treatments. When significant between-group were present, post hoc comparisons were made using Dunnett`s test. Two-Way Repeated Measures ANOVA was conduct to verify the interaction of time and treatment factors. The criterion for statistical significance was $P<0.05$ (α level of 5%).

Results

Twenty-two subjects randomly received all the five test meals and there was no change in the level of physical activity during the experiment. Subject characteristics in the two protocols arms at baseline were not significantly different (Table 2).

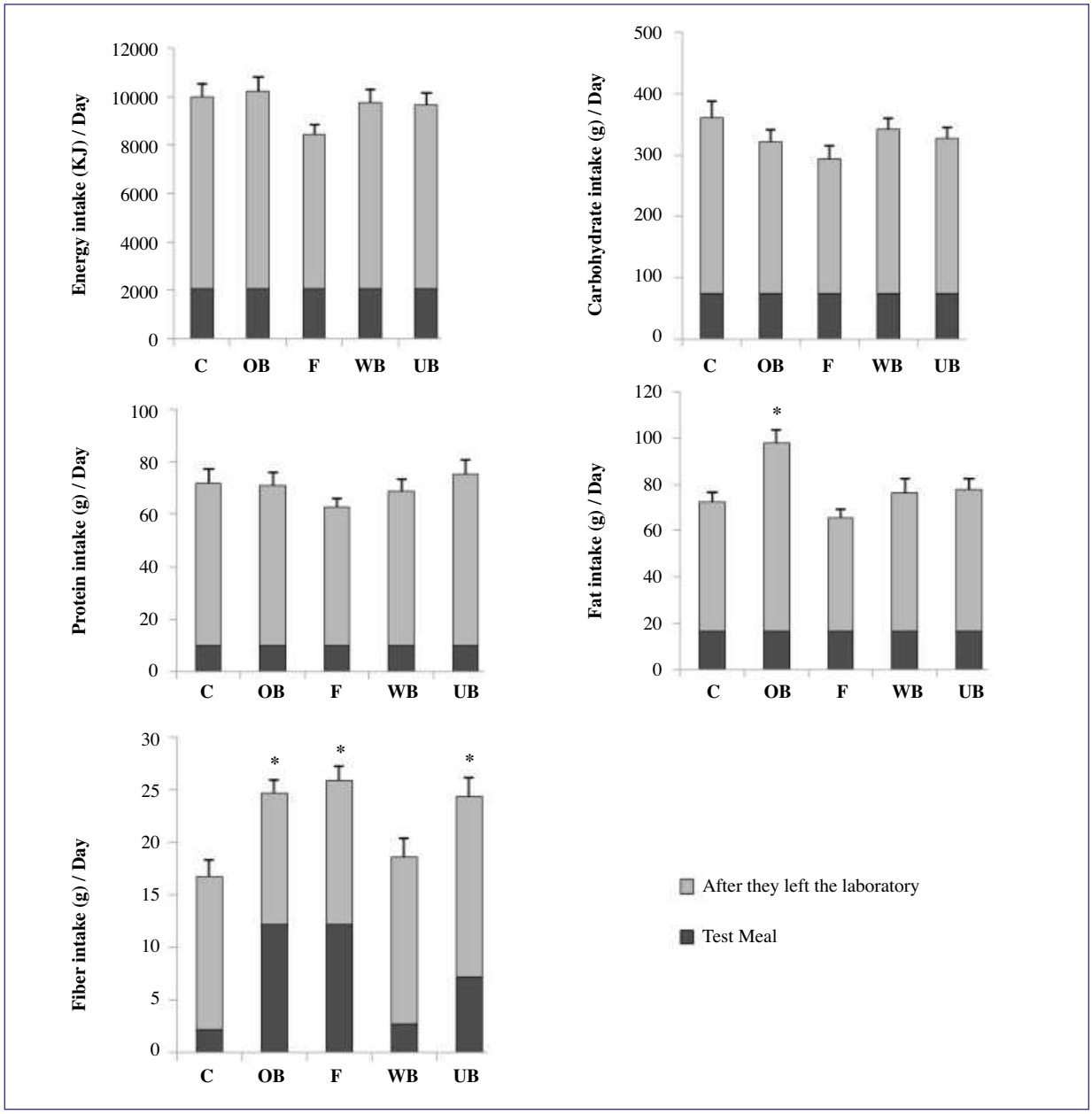

*Fig. 1.—Mean + SEM of energy, carbohydrate, protein, fat, and fiber intake in the days in which liquid meals were consumed (C – control shake; OB - oat bran shake; F – flaxseeds shake; WB - white bean extract shake; UB – unripe banana flour shake). *Mean values are significantly different from the control (one-way ANOVA followed by Dunnett`s test, P<0.05).*

Fiber intake was significantly (P<0.01) greater in response to OB (+17.9g), F (+19.1g), and UB (+12.6g) consumption than C. Also, OB consumption increased the fat intake compared to C (+25,4g; P=0.01). Although daily energy intake in F was 1524kJ lower than in C, this reduction was not significant (P=0.10) (Fig. 1).

The glycemic response was not affected by the test meals at any time point. However, the mean iAUC obtained for UB was 43% lower (P=0.03) compared to the one obtained for C (Fig. 2).

Discussion

The addition of oat bran, flaxseed and unripe banana flour to shakes increased dietary fiber intake by the subjects. The American Dietetic Association – ADA targets a daily dietary fiber consumption of 14g per 4184kJ[22]. Considering the subject´s mean daily energy intake of this study (11650kJ, estimated fiber intake demand of 39g/d) on the day that the C was consumed, the increase in fiber intake in OB (final amount of 36.9g), F (38.1g), and UB (31.6g) was almost enough to meet ADA`s daily targets for fiber intake. It must be considered however that these flours were added into only one daily meal. Its addition to other meals during the day may be a strategy to raise dietary fiber intake and reach the targets.

There was a non-significant reduction of 1524kJ in mean energy intake after the consumption of F, compared to C. However, if this reduction is maintained in a long-term basis it could result in clinical benefits[23]. The reduction of 2000 kJ per day in total energy intake results in a weekly weight loss of 0.5 kg[24]. Therefore, it would be expected a weight loss of about 0.380 kg per week or approximately 1.500 kg per month in response to the consumption of F compared to C. The consumption of flaxseeds could increases satiety and reduces energy intake on the next meal and this effect is related to its fiber and long-chain n-3 polyunsaturated fatty acid content[25,26]. However, the consumption of defatted flaxseeds, and not whole flaxseed, increased serum leptin levels with potential benefit in reducing food intake[27]. These results suggest that the presence of fiber in flaxseeds has more influence than its fat content on food intake.

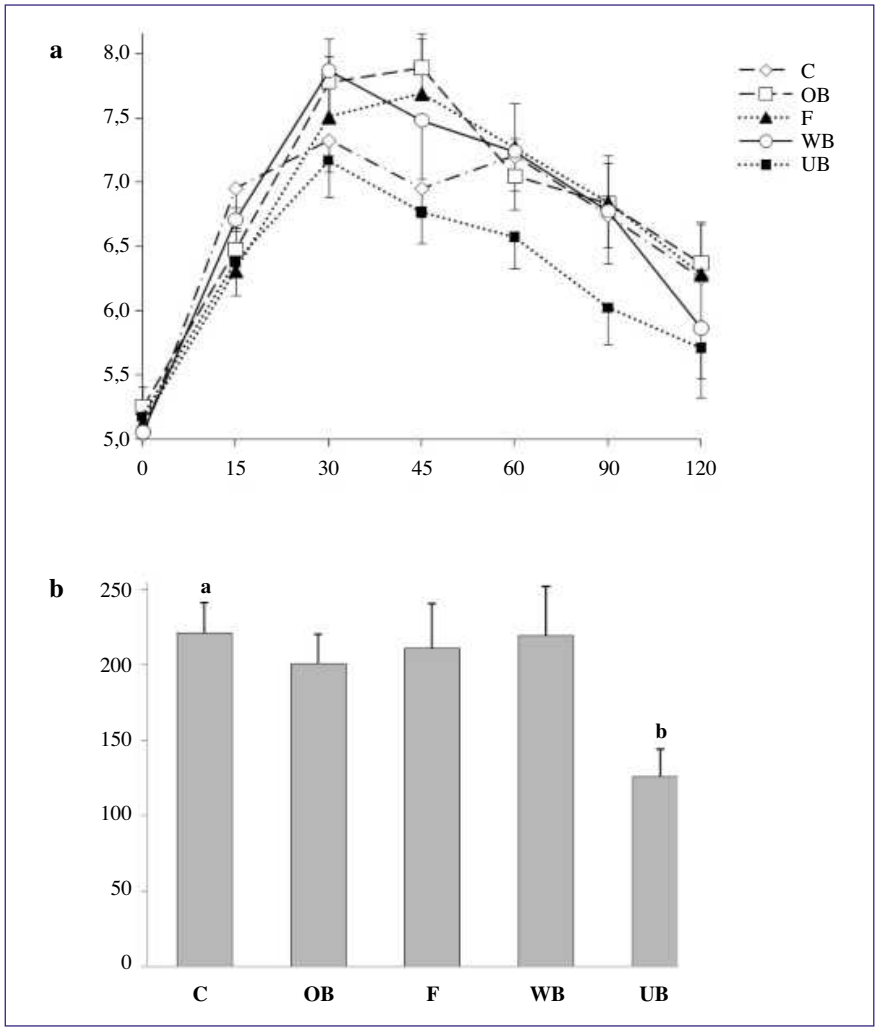

Fig. 2.—Mean + SEM postprandial glucose response (0–120 min) (a), and postprandial incremental area under the curve (iAUC) (0–120 min) (b), obtained after the consumption of liquid meals (C – control shake; OB - oat bran shake; F – flaxseed shake; WB - white bean extract shake; UB - unripe banana flour shake). (a) The glycemic response was not affected by the test meals at any time point. (b) Different letters indicate statistical difference (one-way ANOVA followed by Dunnett`s test, P=0.03).

Despite the same energy and macronutrients contents of all shakes tested, there was an unexpected higher dietary fat intake after OB consumption, compared to C. To our knowledge, this effect has not been observed in any other study. Evidence shows that higher viscosity meals hinds the hydrolysis of fat to non-esterified fatty acids, reducing the secretion of gut hormones such as cholecystokinin (CCK), glucagon-like-peptide-1 (GLP-1), YY peptide, which can lead to increased dietary intake[8]. Further investigation is needed to better understand the effect of oat bran on food intake.

Unripe banana flour is a good source of carbohydrate[28]. It contains about 74.0% of starch, 56.3% as available carbohydrate and 17.5% as resistant starch[29]. Moreover, most of the available carbohydrate is represented by slowly digestible starch. Therefore, this flour can be added to different kinds of preparations as a carbohydrate source that can lead to a lower postprandial glycemic impact[30-32].

It has been shown that the inclusion of unripe banana flour in spaghetti[30], noodles[31], and cookies[32,33], decreased the rate of in vitro starch hydrolysis and the glycemic index prediction[30-33]. The capability of this flour to reduce glycemic response was also observed in humans[33]. Two types of flours (one from unripe banana mass and another from unripe banana starch) were tested in healthy volunteers. There was a reduction of 40.5% and 89.5% in the iAUC, for unripe banana mass and unripe banana starch flours, respectively[33].

Resistant starch has been considered a dietary fiber due to its resistance of gastrointestinal digestion[5]. Its content in unripe banana flour depends on the genotype, maturation degree, and processing method of bananas[28]. Unfortunately, standardized methods for measuring resistant starch are not available[21]. Due to that, resistant starch could be erroneously considered as available carbohydrate[34], leading to lower glycemic responses then the expected. Therefore, considering the resistant starch content previously indicated[29], it is possible that the total available carbohydrate of the UB was underestimated in the present study. In other words, the available carbohydrate content of the UB may have been equivalent to 67.0g instead of 75.0g as initially planned, considering that 45.5g of carbohydrate from unripe banana flour had 17.5% (7.9g) of resistant starch[29]. As small changes in the available carbohydrate content of a food are linearly related to its glycemic response[35], a reduction of about 11% in the glycemic response would be expected after the UB consumption if its carbohydrate content was indeed 67.0g instead of 75.0g. However, the iAUC obtained for UB was 43% lower than the one verified for the C meal. This result suggests that the impact of unripe banana flour on postprandial glycemia is not fully explained by resistant starch content. Further studies are necessary to better understand the mechanisms responsible for this effect.

Glycemic response was not affected by F, OB, and WB. The role of flaxseeds on postprandial glycemia remains inconsistent and the results of human intervention studies show the existence of a modest effect[11,36-38]. On the other hand, oat bran is capable to decrease post-prandial glycemia due to its β-glucan content, which can delay gastric emptying, reduce gut motility, and diminish glucose absorption[39]. Nevertheless, gut transit time of liquid meals may not be enough to augment soluble-fibers viscosity of flaxseeds and oat bran responsible for the hypoglycemic effect.[40] White bean extract, prepared according to package instructions, was also unable to decrease post-prandial glycemia in this study. The hypoglycemic effect of the white bean extract was detected in some but not all studies[13,7]. Since the phaseolamin content is affect by manufacturing process[41], the phaseolamin content in the white bean extract used in this study could not be sufficient to decrease post-prandial glycemia.

Conclusions

The addition of oat bran, flaxseed and unripe banana flour to shakes increased daily dietary fiber intake compared to C consumption. UB led to a 43% post-prandial glycemic response reduction compared to C. There was an unexpected increase in the daily fat intake in response to the consumption of OB. Despite the reduction of 1524kJ in daily energy intake with F consumption, there were no significant differences among treatments. Long-term studies are needed to verify the viability and benefits related to consumption of these flours on obesity and diabetes control.

Conflict of interest

The authors declare that they have no conflict of interest.

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