The effect of soy addition on the satiety, glycemic index, and insulinemic index of a soft pretzel

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Abstract

The contribution of calories from nutrient-poor snack foods is rising in many Western diets, possibly contributing to the increasing prevalence of obesity and diabetes. Soy offers unique potential to provide high quality protein, dietary fiber, and phytochemicals to snack foods to produce a more healthful nutritional profile. In this study, 27.3% of wheat flour was replaced with soy ingredients in a soft pretzel in order to observe the changes in the product's satiety, glycemic index (GI), and insulinemic index (II). First, the soy pretzel was tested for consumer acceptability by 51 untrained sensory panelists on a 9-point hedonic scale. Second, in a crossover trial, 20 healthy adults consumed soy and traditional pretzels (1000 kJ or 239 kcal each) after an overnight fast. They reported their levels of satiety on a 10 cm visual analogy scale (VAS) for 2 hrs postprandially. Third, 12 healthy, non-diabetic subjects consumed soy or traditional pretzels (50 ± 2 g available carbohydrates) to determine the GI and II of both products. Blood glucose and insulin responses were monitored for 2 hrs after consumption and compared to a glucose reference. It was found that the consumer-acceptable soy soft pretzel has a lower GI than its traditional counterpart [39.1±20.4 (mean±SD) for soy and 66.4±15.3 for wheat, p=0.002]. On the other hand, soy addition did not statistically affect II (p=0.15), or satiety (p=0.91). In conclusion, a soy pretzel formulation with 27.3% of wheat flour replaced by soy ingredients leads to attenuated postprandial glycemia without significantly affecting insulinemia or satiety in healthy adults.

Introduction

Snacks are loosely defined as calories consumed at occasions other than breakfast, lunch, and dinner [1]. People in the United States are consuming up to 24% of their calories from snacks on average, a significant increase from last few decades [1]. The increase in food consumption frequency without a compensatory reduction in consumption at each eating occasion may be contributing to the incidence of obesity and type 2 diabetes [2]. Moreover, current snack food choices made by consumers tend to be high in fats and added sugars, contain highly processed carbohydrates that tend to spike blood glucose levels, and contain few essential nutrients [1]. Habitual consumption of foods with these properties can additionally increase risk for chronic diseases such as cardiovascular disease and type 2 diabetes [3]. Therefore, snack foods offer an opportunity to be engineered to include nutritious ingredients to potentially impact the quality of the typical American diet.

Soy addition to snack foods can provide nutritional benefits such as high quality protein, fiber, and various micronutrients [4,5]. It has been shown that soy products can contribute to increased satiety [6,7] which may reduce energy intake and rates of obesity [8]. In addition, diets high in soy protein may contribute to lower incidences of coronary heart disease [4]. Soy is the only non-animal food source that provides all 20 amino acids while remaining low in saturated fat and cholesterol [9]. Soy flour can contain up to 17% dietary fiber including both soluble and insoluble fibers which may lower total and low density lipoprotein (LDL) cholesterol [10]. Additionally, soy isoflavones have been shown to reduce occurrences of hormone-related cancers such as breast cancer [11].

Grain-based snacks such as crackers, pretzels, and other bakery products are popular and offer a promising matrix for the delivery of soy. However, soy addition poses challenges for bakery products [5,12]. In bread, soy protein strongly binds water and dilutes the gluten matrix, decreasing loaf volume [13]. However, baked snack foods such as pretzels (soft and hard), breadsticks, and crackers have a denser matrix which can accommodate increased soy and therefore provide a more promising consumer-acceptable delivery system.

The glycemic index (GI) of a food is defined as the area under the curve of glycemia vs. time (2 hrs) immediately following consumption of 50 g available carbohydrates from the test food, compared to 50 g pure glucose [14]. The insulinemic index (II) is acquired and assessed with a protocol analogous to that of the GI and is used to compared postprandial insulin responses [15]. Foods that are composed of sugars and refined grains generally possess high GI values (≥70) while foods with a lower amount of processed carbohydrates have low GI values (≤55; [16]). Because habitual consumption of high GI foods has been associated with increased risk for type 2 diabetes [17], coronary heart disease [18], and increased appetite that may contribute to obesity [16], there is a need to increase the availability of low GI snack foods [19]. To our knowledge, there has not been a study performed in baked products that has evaluated the effects of soy addition on satiety, GI, and II.

The purpose of this investigation was to evaluate the acceptability of a soft pretzel formulated with 27.3% soy (dry weight) and determine the GI, II, and satiety of the soy-based soft pretzel compared to a conventional wheat soft pretzel. We hypothesized that this substitution would lead to an increase in satiety and a decrease in GI and II in a soft pretzel. We predict that results from this study may be able to translate to other grain-based snack foods.

Experimental

Sensory analysis, glycemic/insulinemic, and satiety studies were approved by the Institutional Review Board at The Ohio State University and were carried out at the Clinical Research Center at The Ohio State University, Columbus, Ohio.

Pretzel production

Soy and wheat pretzels were produced using ingredients in Table 1. Wheat flour (350 g), the dough conditioner, the wheat gluten, and 325 g water were added to a KitchenAid mixer and stirred until moistened. To produce the sponge, the dough was proofed at 39°C at 100% humidity for 2 hrs (CM2000 Holding/Proofing Combination Module; InterMetro Industries Corp., Wilkes-Barre, PA). The remaining ingredients except the shortening were added and stirred with the mixer for about 10 min. The shortening was added and the dough was blended until it sheeted.

Ingredient	Source	Soy Pretzel (g)	Wheat Pretzel (g)
Instant Yeast	Lesaffre Yeast Corporation, Milwaukee WI	3.3	3.3
Bread flour	ConAgra Mills, Omaha NE	453	624.3
Vital Wheat Gluten	Bob's Red Mill, Milwaukie OR	10.0	10.0
Dough Conditioner	The Prepared Pantry, Rigby ID	1.3	1.3
Soy Flour	ADM, Protein Specialties Division, Decatur IL	127.5	-
Benesoy Soymilk Powder	Davansoy, Inc., Carroll IA	42.5	-
Iodized Salt	US Foodservice, Inc., Columbia MD	8.0	8.0
Pure Granulated Sugar	US Foodservice, Inc., Columbia MD	25.0	25.0
Vegetable Shortening (Crisco®)	The J.M. Smucker Co, Orrville OH	20.0	20.0
Water		415 ± 10	405 ± 10

Table 1. Wheat and soy soft pretzel formulations.

Dough was rolled into approximately 60 cm ropes and formed into a soft pretzel shape. The pretzel was dipped into 1.0% sodium hydroxide (65 ± 5°C) for 45-60 sec and placed on a greased baking sheet (Pam 100% Canola cooking spray; ConAgra Foods, Omaha, NE). The pretzels were proofed for 30 min more then baked at 150°C for 15 min (JA14 Jet-Air oven; Doyon, Linière, QC, Canada).

To determine the exact energy density, baked pretzel was dehydrated in a 60°C cabinet (Curtin Matheson, Huston, TX) for 48 hrs and subjected to bomb calorimetry (Parr Adiabatic Calorimeter, Moline, IL). Benzoic acid was used to determine calorimeter efficiency.

Sensory Analysis

Male (19) and female (32) participants between the ages of 18 and 45 yrs were recruited from The Ohio State University campus to complete the sensory analysis. Samples were prepared by placing fresh pretzel pieces (less than 24 hr old) into 2 oz translucent plastic portion cup labeled with a random 3-digit number. The participants consumed samples of either a soy or wheat pretzel in random order (counterbalanced) in ambient lighting. The participants reported their level of acceptability on a 9-point hedonic scale with “1”, on the left, being “extremely dislike”, “5” being “neither like nor dislike”, and “9”, on the right, being “extremely like”.

Study 1- Glycemic and insulinemic indices

The GI and II protocols were based on those detailed in Brouns *et al.* [20]. Pretzel dough totalling 63.8 g (25.0 ± 1.0 g available carbohydrates; [20]) was used to prepare pretzels for the GI and II studies. Participants consumed 50.0 ± 2.0 g available carbohydrates from the soft pretzels in the form of 2 soft pretzels (available carbohydrates = total carbohydrates – dietary fiber). Table 2 shows the energy and macronutrient profiles of the dough. Baked soft pretzels were stored at -40°C and thawed at room temperature the day before consumption.

Eligibility criteria for enrollment included healthy nonsmokers age 18-45 yrs with a body mass index (BMI) less than 30 and without a history of diabetes, glucose intolerance, gastrointestinal disorders, or wheat or soy allergies. After an overnight fast, participants arrived at the Clinical Research Center (CRC) at The Ohio State University. Their vital signs and weight were recorded and they rested for 30 min. During this time an intravenous catheter was inserted into the medial cubital vein in the left or right arm. At time t=0, a blood sample was drawn and, subsequently, they consumed either a glucose standard drink (Glucola, NERL Diagnostics LLC, East Providence, RI), white bread (Giant Eagle King Size enriched bread, Pittsburgh, PA), a soy pretzel, or a wheat pretzel, each containing 50 g available carbohydrates. The glucose drink was consumed three times- at the first session, the last session, and either session 3 or 4. The solid samples were all consumed once, the order determined by randomized block. Blood samples were drawn at t = 15, 30, 45, 60, 90, and 120 min. At least one week separated each visit.

Blood samples were frozen the day of collection and analyzed in a single batch. A YSI 2300 State Plus Glucose and Lactate Analyzer with a sensitivity of 2.5 mg/dl was used to determine glycemia (YSI International, Yellow Springs, OH). Insulin concentrations were determined with an Immulite 1000 chemiluminescence method (Siemens Medical Solutions Diagnostics; Duluth, GA). This assay has a sensitivity of 2 μIU/mL, an intra-assay coefficient of 5.7%, and an inter-assay coefficient of 6.7%. Graphs of glycemia or insulinemia vs. time were generated and the area under the curve (AUC) was calculated for each by measuring the area above the baseline [20]. The average of the AUCs for the three glucose standards was deemed a GI of 100; the same was performed for insulin. The GI and II were reported as the percent AUC as compared to the glucose standard. White bread served as a methods validation.

Study 2- Satiety Study

The satiety experiment employed a randomized, counterbalanced, cross-over design similar to that in Holt *et al*. [8] except satiety values were compared between treatments instead of compared to a glucose treatment.

	Study 1 Glycemic/Insulinemic Index		Study 2 Satiety	
	Soy	Wheat	Soy	Wheat
Calories (kcal)	332.1	270.8	239.0	239.0
Fat (g)	5.2	3.4	3.7	3.0
Carbohydrates (g)	54.7	51.4	39.4	45.4
Fiber (g)	4.7	1.4	3.4	1.2
Protein (g)	17.2	8.1	12.4	7.2

Table 2. The nutrition composition of the pretzels for studies 1 and 2.

Soy dough was weighed to 99.0 g and wheat dough to 98.5 g to assemble soft pretzels with 500 kJ (119.5 kcal) of energy (Table 2). Each participant consumed 1000 kJ per session in the form of 2 fresh pretzels (less than 48 hrs old).

Eligibility criteria included healthy adults age 18-45 yrs with no wheat or soy allergies. Pregnant women were excluded due to fasting requirements and to prevent any unknown risk to the fetus. Participants were randomly assigned to one of two groups; one group consumed the soy pretzel on day 1 while the other group consumed the wheat pretzel on day 1. After an overnight fast (10-12 hrs) and immediately before breakfast, participants were instructed to report their state of hunger on a 10 cm visual analogue scale (VAS) by placing a vertical line on the scale. The scale was flanked by "Extremely hungry" on the left and "Extremely full" on the right [21]. The participant then consumed either the wheat or the soy pretzel, as instructed by the study designer. The participants were instructed to eat the pretzel as is, without any alterations such as heating or toasting or additions including salt or mustard. The participants then reported their satiety on congruent VASs 15 min, 30 min, 1 hr, 1.5 hr, and 2 hr later. During the 2 hr period they were instructed to refrain from eating and drinking anything besides water. They were asked to report approximately how much water they drank during the 2 hrs. The participants were allowed to eat or drink *ad libitum* for the rest of the day, although alcohol was discouraged. That night, the participant again fasted for 10-12 hrs and repeated the procedure the following morning for the other type of pretzel (soy or wheat). For analysis, the distance was measured between the left side of the scale and their vertical line. The data were then normalized by setting the baseline measurement at "0 mm" and the resulting values were plotted vs. time. Using the trapezoid rule, the AUC was calculated for the area above the baseline [20]. Both the satiety declarations at each time point and the AUC of satiety vs. time were used in the statistical assessment.

Statistics

Differences between the soy and wheat soft pretzels were calculated for acceptability, GI, II, satiety values (AUCs), and water consumed during the satiety experiment using a paired, two-tailed Student's *t*-test using Microsoft® Office Excel® 2007. Individual time points of glycemic and insulinemic indices were analyzed using analysis of variance (ANOVA) with the model Y = Type + Participant + Time + Type*Time where Y = glycemia (mg/dl) or insulinemia (μIU/ml); Type = soy or wheat; Participant is 1-12; and Time = 0, 15, 30, 45, 60, 90, or 120 min with SAS statistical software (SAS 9.2 TS2M0, SAS Institute, Inc., Cary, NC). Individual satiety scores at each time point were evaluated also with SAS using the model Y = Time + Type + Particpant where Y = satiety; Participant = 1-20; and Type and Time are the same as above. Statistical significance was deemed at $p < 0.05$.

Results

No adverse effects were observed for any of the participants for any of the studies.

Sensory analysis

Male (19) and female (32) participants between the ages of 18 and 42 yrs (average age 26.6) rated the soy and the wheat pretzels for acceptability. The acceptability of the soy-based soft pretzel was 6.6 ± 1.1 (mean ± SD) and the acceptability of the wheat pretzel was 6.7 ± 1.2 (mean ± SD, $p = 0.59$, two-tailed paired Student's *t*-test). In words, these ratings fall between "slightly like" and "moderately like".

Study 1- Glycemic index study

Thirteen participants were screened and 100% were eligible. One 29 yr. old male dropped out before the study began for personal reasons. Six recruits were male and 6 were female; 1 was East Asian and 11 were Caucasian. The age range was 19-33 yrs with the average (± SD) being 23.8 ± 4.5 yrs.

In Study 1, the GI and II were determined and compared for the wheat and the soy-added soft pretzels. Baseline glycemia values were not different across treatments (p = 0.69, ANOVA). The GI curves varied considerably from person to person with the maximum standard deviation for a single time point at 22.61 mg/dl (Figure 1a). The participant-averaged blood glucose maximum was lower for the soy pretzel than wheat pretzel (112.0 ± 15.1 mg/dL for soy vs. 119.1 ± 16.8 mg/dL for wheat; mean ± SD, p = 0.10, Student's paired two-tailed t-test).

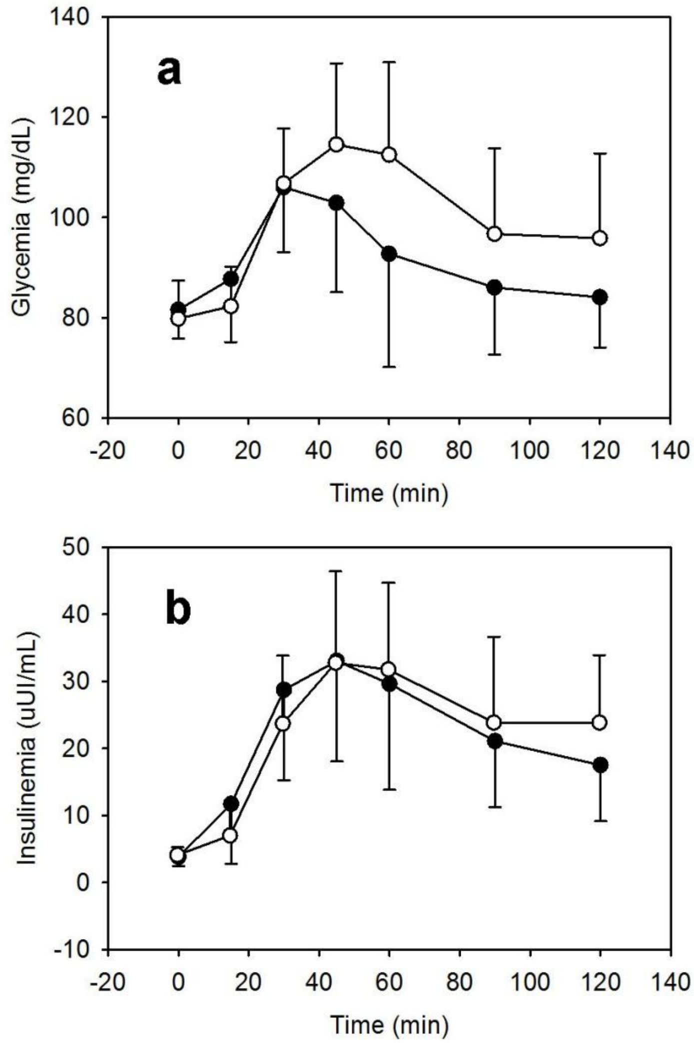

Figure 1. Postprandial glycemia (a) and insulinemia (b) vs. time averaged across 12 participants (●=soy, ○=wheat). Error bars represent the standard deviation of participant distribution.

The GI was calculated by measuring the AUC of the glycemic response compared to glucose. The participant-averaged GI for the wheat pretzel was 66.4 ± 15.3 (and that for soy was 39.1 ± 20.4 (mean ± SD; $p = 0.002$, paired two-tailed Student's *t*-test).

To confirm the reliability of this protocol, the GI for white bread was calculated and compared with literature values. The calculated GI for white bread, 60.4 ± 19.8 (mean ± SD), is consistent with average GI from multiple laboratories (75 ± 2) as reported by Atkinson *et al.* [22].

To calculate II, the AUC for insulinemia vs. time was calculated for the test foods and compared to that of the glucose standard. As a methods confirmation, white bread resulted in an II of 62.8 ± 18.9 (mean ± SD), consistent with reported value of 69 ± 24 from Oku *et al*. for white bread [23]. The II for the wheat pretzel was 79.0 ± 22.6 (mean ± SD) and for the soy pretzel was 75.0 ± 19.6 (mean ± SD, p=0.44, two-tailed, paired Student's *t*-test).

Study 2- Satiety

In Study 2, participants consumed 1000 kJ (239 kcal) of energy from pretzels for breakfast to assess their relative satiety levels. Twenty participants, 8 males and 12 females, aged 20-43 yrs [average age (± SD) = 25.3 ± 6.4 yrs] were recruited from The Ohio State campus for the satiety study. All screened applicants were eligible and 100% of participants completed the study. The maximum feeling of satiety was similar for soy and wheat pretzels (3.62 ± 1.98 cm for soy vs. 3.59 ± 2.65 cm for wheat; $p = 0.96$, two-tailed, paired Student's *t*-test) but occurred sooner for the wheat (15 min vs. 30 min). The feeling of satiety remained the same between 15 and 30 min and subsequently decreased at the same rate for both wheat and soy pretzels and yielded equivalent total satiety scores (AUC = 306.2 ± 215.0 cm*min for wheat, 311.3 ± 201.0; $p = 0.92$, two-tailed, paired Student's *t*-test). When individual time points were compared, the largest difference was between soy and wheat pretzels at 120 min (1.15 ± 2.26 cm for soy and 0.88 ± 2.67 cm for wheat, $p = 0.59$), but there were no statistical differences in satiety values at any one time point ($p \geq 0.59$, ANOVA).

Discussion

An increase the nutritional content of processed bakery products has potential to increase the overall nutritional profile of the average American's diet [24]. The addition of soy to the diet can provide high quality protein, fiber, and potential physiological effects such as reduced postprandial glycemia [25] and increased satiety [6,7], as well as an improved blood lipid profile [4]. In particular, it has been shown that low GI diets and high protein diets can facilitate weight loss in both adults [26] and children [27] as well as facilitate living with diabetes [28].

In this novel study, consumer acceptability of the soy-based soft pretzel was compared to the traditional soft pretzel. Both pretzels were rated between "slightly like" and "moderately like" on a 9-point hedonic scale by 51 volunteers, showing that the soy pretzel is a consumer-acceptable substitute for the traditional soft pretzel. Several published studies have shown that soy flour is not accepted in concentrations over about 10%, [12,29], however, in accord with our results, Sabanis & Tzia (2009) utilized soy milk powder to incorporate up to 20% soy ingredients into bread while maintaining favorable sensory attributes in a Greek population. In addition, a chewy texture and darker brown color (imparted by the lye bath), while generally not acceptable in bread, is an affirmation of quality in soft pretzels by consumers.

In the glycemic/insulinemic index study (Study 1), both pretzels were composed of 50 g available carbohydrates (total carbohydrates - undigestable carbohydrates). Because the soy pretzel formulation contained about 20% less starch per gram, each soy pretzel contained 61.3 kcal, 1.8 g fat, 3.3 g fiber, and 9.1 g more protein than the wheat pretzel (Table 2). We found that this soft pretzel, composed of 27.3% soy ingredients, decreases the GI of a wheat-based soft pretzel from 66.4 ± 15.3 ("moderate GI") to 39.1 ± 20.4 ("low GI", [16]; $p = 0.002$).

Reduced glycemia can arise from reduced rate of glucose introduction to the blood, increased rate of glucose uptake by tissues, or both [30]. It is likely that at least the former mechanism is involved in the reduced glycemic response to the soy pretzel. The larger amount of total food in the stomach with the soy pretzel likely slowed the transit time from stomach to small intestine, reducing the rate of carbohydrate availability for absorption. The insulin secretogenetic properties of protein may also have contributed to an increase in the rate of glucose uptake by hepatic and somatic body cells. Insulinemia has been shown to be higher after a meal with a whey protein pre-load, leading to attenuated post-prandial glycemia [31]. A change was not observed in insulin responses for the soft pretzels but there is a chance that the soy ingredients led to an increase in the flux or the efficiency of the insulin response pathway. Increased insulin sensitivity has been observed with long-term interventions with soy (Ascencio *et al.*, 2004), but the response of body cells to insulin after acute doses of soy has not yet been investigated.

Despite the attenuated glycemic response, the rate of insulin secretion was not significantly different between both pretzels. Although the carbohydrate concentration is diluted in the chyme, protein and lipid also stimulate glucagon-like peptide-1 (GLP-1) and glucosedependent insulinotropic polypeptide (GIP) which stimulate the release of insulin. This finding is consistent with the observation that high protein foods such as lentils elicit insulin responses greater that that predicted from the glycemic response [15].

In the satiety study (Study 2), soy and wheat pretzels containing exactly 239 kilocalories (1000 kJ) were consumed by 20 volunteers. Despite the soy pretzel having 5.2 more grams of protein and 2.2 more grams of fiber than the wheat pretzel, there was no statistical difference in the feeling of satiety (Figure 2). There were likely counteracting factors that led to this observation. Protein both stimulates the release of cholecystokinin (CCK), which inhibits gastric emptying CCK [32]. The increase in fiber can increase chyme viscosity, which leads to slowed gastric emptying and/or an increase in thirst which expands the stomach, leading to release of CCK, thus increasing satiety [6,33]. However, the wheat pretzels were larger in appearance due to the facilitated formation of air cells from higher gluten concentrations, and may have subconsciously increased satiety [34]. A study that can control for physical activity, food intake on days before the experiment, alcohol consumption, and sleep amount and quality may be

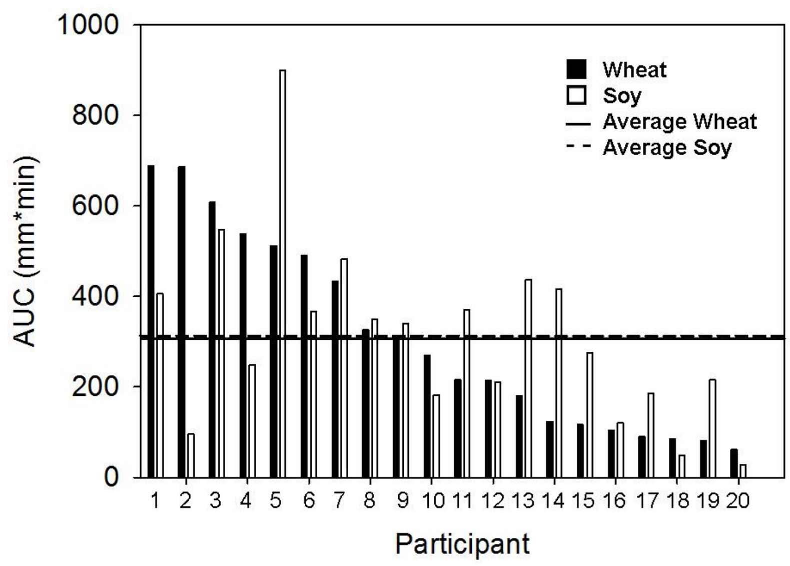

Figure 2. Satiety values for the participants as measured by AUC for satiety score vs. time relative to the baseline. Participants are ordered in descending order for wheat satiety scores.

able to detect subtle differences, if there are indeed any, between the satiety of these snack foods.

In order to control for the initial hunger level of the participants, the satiety study was designed so that the soy pretzel was consumed as the first meal of the day (breakfast) rather than as a snack. It has been estimated that university students, who comprised the majority of this participant pool, consume approximately 15-18% of their total energy intake from breakfast [35]. Assuming 2000 kcal average diets, the 249 kcal soy pretzel might have been less food than their normal breakfast, resulting in insatiety for both pretzel varieties. Hence, future studies investigating satiety of a soy snack food in between meals or as a more appropriately sized breakfast may avoid this complication. It is hypothesized that soy alternatives of grain-based foods that people are consuming already will lead to increased satiety and therefore reduced energy intake and facilitated weight control.

Conclusion

The addition of soy to a soft pretzel snack food can significantly decrease the GI without affecting consumer acceptability or satiety. Soy addition at 27.2% can potentially improve the heathfulness of a wide variety of bakery products and snack foods and impact the food market. These results show that soy can be used to supplement snack foods in high enough quantities to achieve lower postprandial glycemia while maintaining favorable sensory characteristics.

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