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Applied nutritional investigation

The effects of whey and soy liquid breakfast on appetite response, energy metabolism, and subsequent energy intake

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ABSTRACT

Objectives: The aim of this study was to examine the effects of animal-based protein (whey; WP) compared with plant-based protein (soy; SP) and carbohydrate (CHO) liquid breakfast on appetite, energy metabolism, and subsequent energy intake.

Methods: Seventeen healthy individuals consumed three isocaloric breakfast smoothies with whey, soy, or carbohydrate (no protein) in a double-blind, randomized crossover design. Participants completed an 11-point rating scale of appetite profile (before, 0, 60, 120, and 180 min). Indirect calorimetry was used to determine the thermic effect of a meal (TEM; at 45–60, 105–120, and 165–180 min). An ad libitum lunch was offered at 180 min after breakfast and energy intake was assessed.

Results: There was a significant difference in hunger ($P = 0.033$), fullness ($P = 0.002$), satiety ($P = 0.001$), desire to eat ($P = 0.024$), and prospective food consumption ($P = 0.021$) between the three breakfast meals. Fullness and SP compared with CHO. A higher ($P < 0.001$) TEM and lower ($P < 0.05$) respiratory exchange ratio (RER) was observed after WP and SP compared with CHO. In addition, a higher ($P = 0.022$) energy intake at lunch was observed after CHO (769 ± 259 kcal) compared with WP (654 ± 252 kcal) and SP (664 ± 296 kcal), with no difference ($P = 0.966$) between WP and SP. Consuming SP at breakfast exerts comparable effects to WP on appetite profile, energy metabolism, and subsequent energy intake, suggesting that SP is a reasonable alternative to WP as a protein supplement source to aid in body weight control.

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Introduction

Obesity is a major public health concern associated with chronic diseases, including hypertension, type 2 diabetes, coronary heart disease, stroke, cancer, osteoarthritis, sleep apnea, and respiratory problems [1,2]. In the past 30 y, the incidence of obesity, defined as a body mass index (BMI) >30 kg/m^2, has increased dramatically not only in the United States, but also globally [1,3,4]. Although the mechanisms contributing to obesity are complex, it is principally the result of excessive energy intake and insufficient energy expenditure [1,2,5]. It is well documented that dietary protein increases satiety and thermogenesis to a greater extent than carbohydrate (CHO) or fat [6–8] and can therefore reduce energy intake [9,10]. For these reasons, a high-protein diet has recently attracted attention as a potential weight management strategy to promote satiety and increase weight loss through reduced energy consumption [1,6,11,12]. It has been suggested that different protein sources influence satiety and thermogenesis differently; however, studies in humans evaluating this relationship are very limited and the available evidence is inconsistent [6,7,11–15]. Many studies have found greater satiating effects after consumption of animal-based proteins (whey and casein) rather than plant-based proteins (soy, pea protein, and egg albumin) [6,7,9,11,16], whereas others have reported no effect of different protein sources on hunger and satiety [8,15,17–19]. For example, Lang et al. [19] observed no effect of protein source on satiety or energy intake 24 h after ingestion of preloads containing either egg albumin, casein, gelatin, soy protein, pea protein, or wheat gluten. On the other hand, a higher satiety was observed after consumption of casein and soy protein but not after consumption of whey protein (WP) [6]. Tan et al. [8] compared the effects of consuming three isoenergetic meals containing protein from meat, dairy, and soy sources found that all three meals showed an equal capability to increase satiety levels. In addition, Anderson et al. [9] observed suppressed food intake after ingestion of preloads containing 45 to 50 g of whey and soy. Results from studies

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investigating the thermogenic effects of different proteins are also inconsistent. Alfenas et al. [11] observed a higher thermogenic effect after soy protein (SP) compared with WP, whereas Acheson et al. [6] found that WP elicited a greater thermic response than SP. The conflicting findings between these aforementioned studies may be attributed to different study designs, protein content and meal characteristics, and the length of supplement consumption, as well as participant characteristics including age, sex, and level of activity (5,20–22]. In addition, although digestibility of WP and SP is comparable, amino acids from soy are more readily converted to urea and have higher oxidation rates than whey [22], thus higher doses of soy maybe necessary. Such discrepancy indicates the need to conduct additional studies to evaluate the satiating and thermogenic effects of different protein sources.

Considering the possible, yet unclear, effects of protein quality on satiety and energy intake, the present study aimed to investigate the effects of consumption of different protein sources (WP and SP) 3 h after breakfast compared to an isoenergetic control (CHO) using a liquid breakfast meal (smoothie) on appetite, energy metabolism, and subsequent energy intake at lunch. We hypothesized that higher dose of SP would exert similar effects as WP and could therefore be used to suppress hunger and potentially aid in weight management by individuals who choose not to consume animal-based protein. Whey (whey concentrate and whey isolate) and soy isolate proteins were chosen because they are available in almost pure forms in commercially sold products and are types of animal and plant proteins commonly consumed, both naturally and in supplemental form.

Materials and methods

Participants

Seventeen healthy men and women (BMI 24.6 ± 0.9 kg/m^2; 20–41 y of age) were recruited from the local area through word of mouth, e-mails, and flyers posted at local health facilities and shops. Eligibility was determined through the following inclusion criteria:

- age range of 18 to 45 y
- normal to overweight (BMI between 18.5 and 29.5 kg/m^2)
- no metabolic diseases or conditions
- not currently on a weight loss plan or a special diet (in the previous 6 mo)
- nonsmoker (in the previous year)
- habitually eats breakfast (i.e, ≥5 times/wk)
- no food allergies or intolerances to dairy or soy products

Participants were asked to refrain from consuming any nutritional supplements, with the exception of a multivitamin, for 2 wk before their first testing visit as well as for the duration of the study. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the university Institutional Review Board. Written informed consent was obtained from all participants.

Study design

This was a randomized, double-blind, crossover design. Before the start of the study, the participants reported to the laboratory for one familiarization visit of study procedures, metabolic testing, dietary intake recording. and collection of baseline measurements. After completion of the familiarization visit, the participants reported to the laboratory in the morning on three different occasions, with at least a 72-h washout period in between, for measurements and assessments. Anthropometric parameters, body composition, heart rate, and blood pressure (BP) were collected during the familiarization visit. During each of the three testing visits, the participants were given one of three breakfast meals and an ad libitum lunch, while appetite ratings and metabolic testing were assessed for the following 3 h. Energy intake at lunch was measured at 180 min after completion of breakfast.

Visit 1 (familiarization)

Anthropometric parameters. Height (cm) and body weight (kg) were measured via a stadiometer (Seca 700, Hamburg, Germany) and a BF-679W TANITA digital scale (Tanita Corporation of America, Inc. Arlington Heights, IL, USA), respectively. Body composition was assessed using the BIA 450 Bioimpedance Analyzer (Biodynamics Corp, Shoreline, WA, USA) with participants in a supine position to determine body fat percent, BMI, and estimate basal metabolic rate.

Measurement of heart rate and BP. After 5 min of seated rest in a quiet room, resting heart rate was measured manually. BP was measured with a manual sphygmomanometer (American Diagnostic Corp, Hauppauge, NY, USA) and a stethoscope. The same technician took both heart rate and BP for each participant.

Visits 2 to 4 (testing)

During each of the three testing visits, laboratory testing was conducted in the morning between 0600 and 0900 h after a 10- to 12-h fast (water was allowed) and at least a 12-h restriction of physical activity, alcohol, tobacco and caffeine intake. Total energy intake and protein intake 24 h before each testing session was assessed using a smartphone application MyFitnessPal (Under Armour Inc, Baltimore, MD, USA). Figure 1 provides a detailed overview of the test-day timeline.

Breakfast and lunch meals. The three breakfast meals were provided as smoothies, each containing 1 cup (240 mL) vanilla coconut milk, 130 g bananas, 70 g frozen raspberries, and $^1/_4$ cup (60 mL) water with either mixed whey powder (whey concentrate and isolate; chocolate supreme), soy isolate powder (chocolate supreme), or unflavored/unsweetened carbohydrate powder (Table 1). Previously, suppressed food intake following consumption of higher doses of 45 to 50 g of WP and SP was observed by Anderson et al. [9] and Ryan et al. [23]. Therefore, a double dose of the suggested serving for WP (~ 43 g) and Sp (~50 g) was chosen based on the commercially available product. Similarly to the previous research, CHO (control) was chosen owing to increased contribution of total calories and added sugars consumed in the modern diet [6,11,24]. In addition, to standardize flavor among all three meals, the CHO breakfast meal was flavored with a commercial, unsweetened cocoa powder. Liquid breakfast meals were chosen because of previous evidence suggesting that homogenization delays the gastric emptying rate and can show favorable effects on appetite ratings, thermogenesis, and energy intake [25].

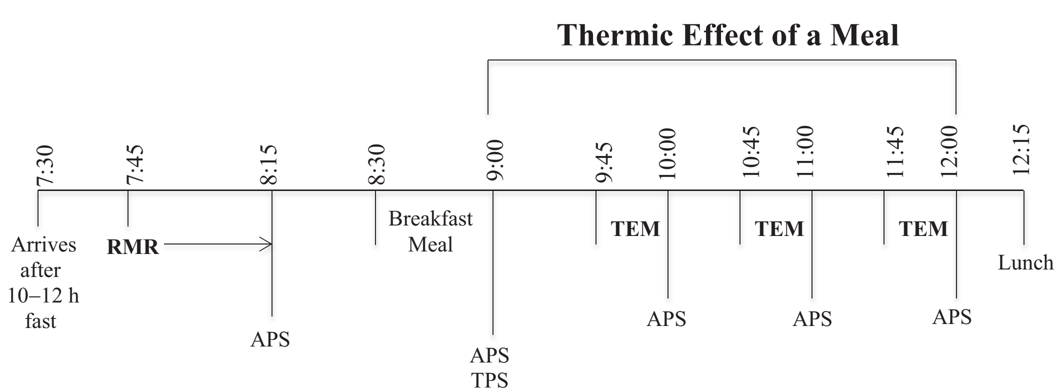

Fig. 1. Test-day timeline. Both scales were rated on a 0–10 scale. APS, appetite profile scale; RMR, resting metabolic rate; TEM, thermic effect of a meal; TPS, taste perception scale.

Three hours after consuming the breakfast meal, participants were provided an ad libitum lunch that consisted of cheese bagel bites. A standardized amount (130 g) of grapes was also provided along with the ad libitum bagel bites. Participants were provided with one plate containing 10 to 12 bagel bites. Participants were instructed to eat until they felt comfortably full and additional bagel bites were given to the participants as needed. Two water bottles (500 mL each) were also provided for the participants to drink throughout the 3-h period.

Assessment of appetite profile. Feelings of hunger, fullness, satiety, desire to eat, and prospective food consumption were assessed using a modified unipolar 11-point scale (0–10) hunger and satiety scale commonly used by health promotion and wellness practitioners [26,27] during the following times: immediately pre-meal and at 0 (immediately post-meal) and at 60, 120, and 180 min after breakfast consumption (Fig. 1). Participants were instructed to rate each appetite sensation corresponding to their feelings at that moment (0 = *not at all* to 10 = *extremely*). Ratings were recorded as whole numbers, with higher numbers indicating greater feelings of each appetite sensation.

Assessment of taste perception. The taste perception of the three breakfast meals was assessed immediately after finishing breakfast (Fig. 1). A 11-point scale, with 0 being *bad* and 10 being *good*, based on previous studies [19,28] was adapted to assess the breakfast meals in terms of pleasantness (palatability, taste, aftertaste, smell, and visual appeal) and taste intensity (sweet, salty, bitter, sour, creamy, savory). Ratings were recorded as whole numbers, with higher numbers indicating greater pleasantness.

Energy intake. The amount of bagel bites and grapes consumed at lunch was measured by weighing the contents of each plate before and after the lunch meal using a digital multifunction kitchen and food scale (Ozeri, San Diego, CA, USA). Total energy intake was calculated by multiplying the difference of the weight of the lunch by the energy value of the lunch as determined by the product labels.

Resting metabolic rate and thermic effect of a meal. Resting metabolic rate (RMR) and thermic effect of a meal (TEM) were measured using the ventilated hood technique with a TrueOne 2400 computerized open-circuit indirect calorimeter (Parvomedics, Sandy, UT, USA). Participants were not allowed to sleep and all measurements were obtained with the participants resting supine on a bed in a dark, quiet, and thermo-neutral room (22 ± 1°C) and wearing a heart rate monitor (Polar, Kempele, Finland) to assess heart rate. RMR (kcal/d) was measured for 30 min before breakfast consumption and measurements recorded in the last 20 min were used for analysis. Indirect calorimetry was also used to measure oxygen consumption (VO_2; mL/min) and respiratory exchange ratio (RER). After the breakfast meal, a postprandial thermogenesis (TEM) was periodically measured for three 15-min time intervals over 180 min (Fig. 1). A 180-min TEM was chosen to capture the majority of the postprandial response (Gentile et al., 2015). Measurements of VO_2 (mL/min) recorded in the final 10 min of each 15-min period were used to calculate the number of calories per minute expended from the oxygen consumption during the postprandial period.

Statistical analyses

Statistical analyses were performed using SPSS version 24 software (IBM, Armonk, NY, USA). Sample size was determined based on a previous study [20] that found a significant interaction in our main outcome (appetite) with an effect size (Cohen's *d*) of 0.34. Based on an α-level of 0.05 and 80% power, a minimum of 12 participants were needed to detect significant differences. Descriptive statistics, means, and SEM were calculated for all variables. A repeated-measures analysis of variance (ANOVA; sex × meal × time) was initially conducted to determine differences among sexes, breakfast meals, and time points. Because there were no differences between the men and women, a 3 × 5 (meal × time) repeated-measures ANOVA was performed to determine the ratings of the appetite profile. Changes in the appetite profile were calculated as the difference between premeal ratings and each postmeal time-point rating (Fig. 2). The Pearson product-moment correlation coefficient was calculated for appetite profile at 180 minutes and energy intake. A 3 × 3 (meal × time) repeated-measures ANOVA was used to determine TEM and RER. Changes of TEM and RER were calculated as the difference between RMR values and each postmeal time point value (Figs. 3 and 4). One-way ANOVAs were used to compare differences between the three breakfast meals for RMR, taste perception, and energy intake. Where significant main effects were observed, Tukey's post hoc analysis was used to locate differences. Significance was set at $P < 0.05$, and data are reported as means with their SE, unless otherwise noted.

Table 1
Nutritional analysis of breakfast test meals

	CHO	SP	WP
Energy (kcal)	471	486	486
Soy protein (g)	–	50	–
Whey protein (g)	–	–	43.3
Total protein (g)	3	52	45.3
Total carbohydrate (g)	105.5	52	58.8
Total fat (g)	6.8	7.5	9.1
Total fiber (g)	7.7	6	7.8
Sugar (g)	27.5	31.5	31.1

CHO, carbohydrate; SP, soy protein; WP, whey protein.

Results

Participants

Baseline physical characteristics of the participants are presented in Table 2 based on sex and the whole group. As expected, men had significantly higher body weight, height, lean body mass, basal metabolic rate, and systolic and diastolic BP, but lower body fat percent than the women. Despite these differences, no differences between men and women were observed in the appetite profile ratings, changes in metabolic measures, or energy intake between the three breakfast meals, and thus men and women were pooled together for all analyses. Total energy intake and protein amount 24 h before the testing session was available for 14 participants and were not significantly different ($P = 0.84$) 1596 ± 696, 1599 ± 488, and 1529 ± 771 kcal and ($P = 0.27$) 68 ± 30:56 ± 29, and 59 ± 42 g between CHO, SP, and WP, respectively.

Appetite profile

Baseline ratings for appetite profile did not significantly differ between the three breakfast meals (Table 3). The perceived appetite ratings of the three breakfast meals completed right after consumption and at 60, 120, and 180 min are shown in Fig. 2. Repeated-measures ANOVA showed significant main effects of meal ($P < 0.03$) and time ($P < 0.001$) on perceived appetite ratings. Post hoc pairwise comparisons revealed that feelings of fullness and satiety were higher after WP ($P < 0.001$) and SP ($P < 0.05$) breakfast meals, whereas reported hunger, desire to eat, and prospective food consumption were lower after WP ($P < 0.05$) but not SP ($P > 0.05$) compared with CHO. No significant differences in any of the appetite ratings were observed between the WP and SP breakfast meals ($P > 0.05$). Regardless of meal (i.e, time effect), all breakfast meals led to immediate increases in feelings of fullness and satiety and decreases in reported hunger, desire to eat, and prospective food consumption (Fig. 2). This was followed by a gradual decline in fullness and satiety and a rise in hunger, desire to eat, and prospective food consumption throughout the subsequent 3-h period (Fig. 2). Appetite ratings, except for fullness and satiety, returned to premeal conditions at 180 min (Fig. 2). Hunger, satiety, desire to eat, and prospective food consumption at 180 min was significantly correlated with food intake at lunch after CHO and SP ($P < 0.05$) but not after WP ($P > 0.05$), whereas fullness was only significantly correlated after CHO ($P < 0.05$) and not after SP or WP ($P > 0.05$).

Taste perception

The ratings of pleasantness of taste, palatability, aftertaste, smell, visual appeal, sweetness, saltiness, bitterness, sourness, creaminess, and being savory were not different between the three breakfast meals ($P > 0.05$; Table 4).

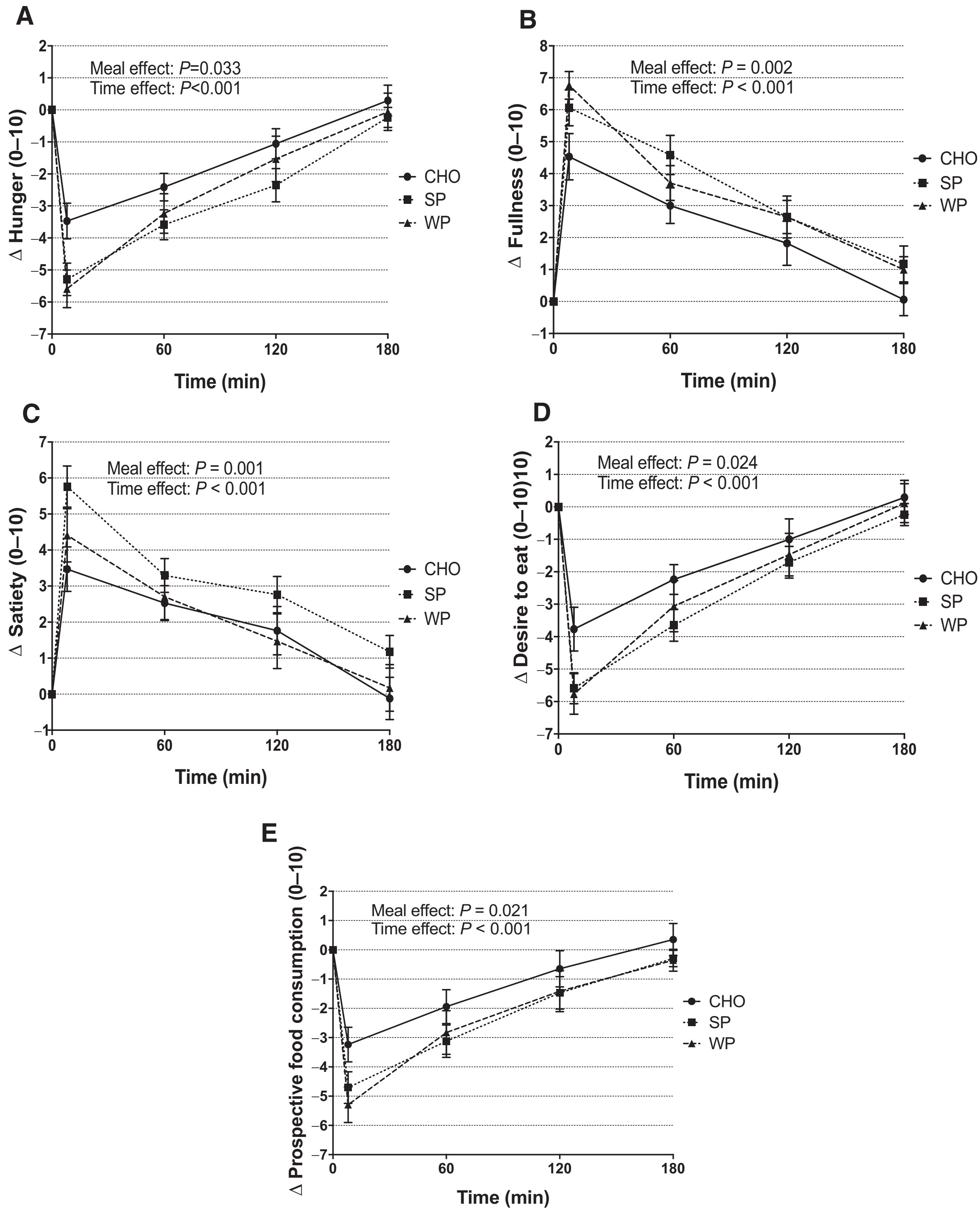

Fig. 2. Effect of breakfast test meals on the hunger, fullness, satiety, desire to eat, and prospective food consumption. The scores are presented as difference in response change over 180-min period compared with prebreakfast test meal. CHO, carbohydrate breakfast meal; SP, soy protein breakfast meal; WP, whey protein breakfast meal.

RMR and TEM

Mean fasting and RMR rates were similar among all three breakfast meals for each participant. Repeated-measures ANOVA showed significant main effects of meal ($P < 0.001$) and time ($P < 0.001$) on TEM measures (Fig. 3). The thermic response was significantly higher after WP and SP ($P < 0.001$) than after CHO (Fig. 3). In addition, there was no significant difference in the thermogenic response between WP and SP ($P = 0.308$). Regardless of meal (i.e, time effect), postprandial thermogenesis increased in a similar manner immediately after consumption of all three breakfast meals (Fig. 3). However, TEM after WP and SP remained significantly higher and did

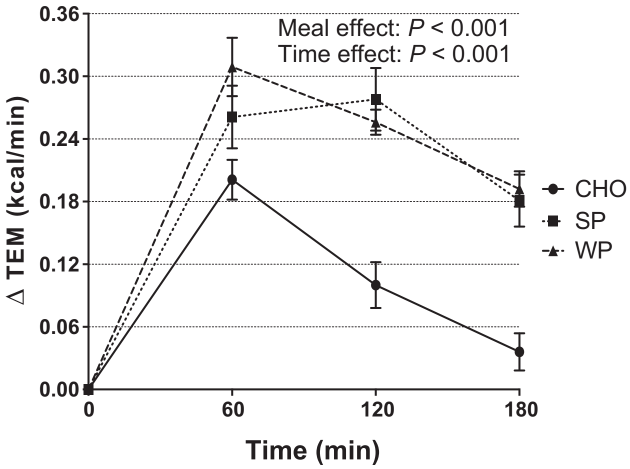

Fig. 3. Effect of breakfast test meals on the thermic effect of the meal. The change over 180-min period compared with RMR. CHO, carbohydrate breakfast meal; RMR, resting metabolic rate; SP, soy protein breakfast meal; WP, whey protein breakfast meal.

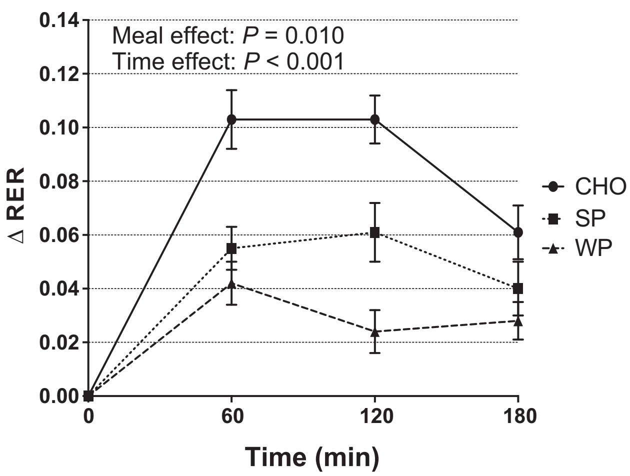

Fig. 4. Effect of breakfast test meals on the respiratory exchange ratio. The change over 180-min period compared with RER. CHO, carbohydrate breakfast meal; RER, resting energy rate; SP, soy protein breakfast meal; WP, whey protein breakfast meal.

not return to baseline, whereas TEM after CHO was lower and returned to premeal conditions at 180 min (Fig. 3). Figure 4 illustrates the effect of the breakfast meals on the RER. The RER was significantly lower after WP ($P = 0.007$) and SP ($P = 0.015$) than after CHO, with the greatest reduction occurring after WP ingestion (Fig. 4). There were also no differences in RER between the WP and SP breakfast meals ($P = 0.364$).

Table 3
Baseline values of appetite profile ratings (0–10 point scale; N = 17)

	CHO mean ± SD	SP mean ± SD	WP mean ± SD
Hunger	7.4 ± 1.7	7.7 ± 1.8	7.1 ± 2
Fullness	1.8 ± 1.7	1.6 ± 1.9	2.1 ± 1.5
Satiety	2.4 ± 2.1	2.1 ± 1.7	3.4 ± 2.2
Desire to eat	7.7± 2.1	7.7 ± 1.7	7.1 ± 2.1
Prospective food consumption	7.2 ± 2.0	7.2 ± 1.3	7.1 ± 1.6

CHO, carbohydrate; SD, standard deviation; SP, soy protein; WP, whey protein.

Table 4
Taste perception ratings (0–10 point scale; N = 17)

	CHO mean ± SD	SP mean ± SD	WP mean ± SD
Pleasantness of taste	5.3 ± 1.9	6.1 ± 2.2	6.6 ± 2.2
Palatability	5.9 ± 1.9	6.4 ± 1.9	6.2 ± 2.4
Aftertaste	4.8 ± 2.0	5.2 ± 2.6	5.9 ± 2.9
Smell	6.3 ± 1.6	6.6 ± 1.9	6.3 ± 2.4
Visual appeal	6.9 ± 2.1	6.0 ± 2.9	6.9 ± 2.4
Sweetness	5.6 ± 2.0	6.3 ± 2	6.9 ± 1.2
Saltiness	5.0 ± 2.0	4.8 ± 2.6	4.6 ± 2.3
Bitterness	4.8 ± 2.1	4.8 ± 2.5	5.2 ± 2.7
Sourness	4.4 ± 1.9	5 ± 2.5	5 ± 2.7
Creaminess	5.4 ± 2	6.2 ± 2.1	7.4 ± 2.1
Savory	5 ± 1.6	5 ± 2.4	6.1 ± 2.6

CHO, carbohydrate; SD, standard deviation; SP, soy protein; WP, whey protein.

Energy intake

Energy intake at lunch (180 min) after each of the three breakfast meals is shown in Fig. 5. Compared with CHO (769 ± 259 kcal), there was a significantly lower energy intake at lunch after consumption of WP (654 ± 252 kcal; $P = 0.020$) and SP (664 ± 296 kcal; $P = 0.033$). There was no significant difference in energy intake at lunch between the WP and SP breakfast meals ($P = 0.799$).

Discussion

The main findings of the present study suggest that liquid breakfast meals with WP and SP led to greater satiating and thermogenic effects and reduced energy intake at lunch compared with CHO. Furthermore, there were no significant differences between the effects of WP and SP consumption on appetite ratings, energy metabolism, or subsequent energy intake at lunch. These results suggest that higher consumption of SP could stimulate satiety and thermogenesis to a similar extent as the consumption of

Table 2
Participant characteristics

	Men (n = 6)mean ± SD	Women (n = 11)mean ± SD	Total Group (N = 17)mean ± SD	*P*-value
Age (y)	28 ± 8	26 ± 6	27 ± 7	0.47
Height (cm)	181 ± 9*	164 ± 5	170 ± 10	<0.001
Weight (kg)	82.6 ± 11*	65.3 ± 14	71.4 ± 15	0.02
BMI (kg/m^2)	25.4 ± 3	24.1 ± 4	24.6 ± 4	0.55
Percent fat (%)	16.1 ± 5**	24.5 ± 6	21.5 ± 7	0.01
BMR (kcal/d)	2154 ± 268*	1516 ± 224	1741 ± 391	<0.001
Systolic BP (mm Hg)	122 ± 7	112 ± 9	115 ± 10	0.02
Diastolic BP (mm Hg)	74 ± 9*	60 ± 9	65 ± 11	0.01
Resting HR (bpm)	64 ± 10	71 ± 13	69 ± 12	0.26

BMI, body mass index; BP, blood pressure; HR, heart rate; BMR, basal metabolic rate; SD, standard deviation.
*$P < 0.05$, significantly different from women.

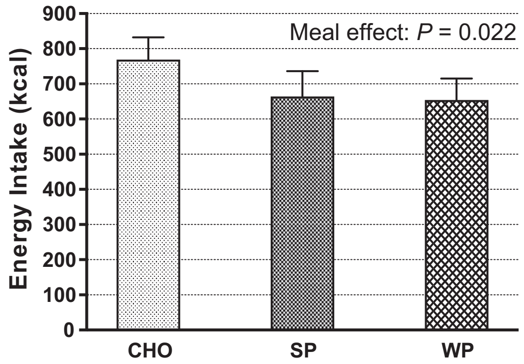

Fig. 5. Effect of breakfast test meals on energy intake at lunch. CHO, carbohydrate breakfast meal; SP, soy protein breakfast meal; WP, whey protein breakfast meal.

WP and also support an argument for using plant-based protein supplementation sources in weight management diets to combat obesity.

In the present study, consumption of both WP and SP liquid breakfast meals led to increased fullness and satiety compared to CHO. Only WP significantly reduced hunger, desire to eat, and prospective food consumption to a greater extent than CHO. These results are in agreement with previous studies that have also reported a higher satiating effect of protein than that of fat or carbohydrate, especially meals with a high (20–30%) protein content [16,21,29–31]. Furthermore, Veldhorst et al. [2,19] suggested that the satiating effects of different proteins might be dose dependent. No differences in satiety were found 4 h after consumption of a mixed breakfast meal containing whey, casein, or SP at 25% of energy intake, an intake considered higher than normal. These results suggest that after a certain amino acid threshold, different proteins have similar satiating effects [19]. This observed dose-dependent effect of different proteins on subjective appetite ratings might partially explain the similarities in satiety seen between WP and SP in the present study because both breakfast meals provided ~36% to 40% of energy intake from the respective proteins. However, this needs to be further investigated because there might be variability within the protein sources itself.

The increased fullness and satiety after the WP and SP breakfast meals coincided with a significant reduction in energy intake at lunch (~100 kcal; $P = 0.022$) compared with CHO. However, the appetite profile was significantly correlated at 180 min postmeal with energy intake at lunch after SP and CHO but not after WP. Nevertheless, the main findings are consistent with previous research that has shown protein to have the most suppressive effect on energy intake compared with fat and CHO [9,32–34]. Furthermore, there was no significant difference in energy intake at lunch after consumption of WP and SP (~10 kcal difference; $P = 0.966$), suggesting that SP may have favorable and similar effects as WP on suppressing food intake. These results coincide with those obtained by Anderson et al. [9], who found no difference in energy intake 1 to 2 h after consumption of WP and SP in the form of isolates. However, breakfast meals are rarely consumed as isolated macronutrients, therefore the use of a mixed breakfast meal in the present study in the form of a smoothie has practical significance. Our findings are also in agreement with Bowen et al. [17], who found that liquid mixed meal preloads containing 50 g of either WP or SP similarly reduced ad libitum food intake in lean and overweight men 3 h after protein ingestion. Likewise, Diepvens et al. [7] also reported no effect on energy intake at lunch after consumption of test shakes containing either WP, pea protein hydrolysate (PPH), a combination of WP and PPH, or milk protein, despite apparent differences in appetite ratings. Thus it appears that at doses between ~40 to 50 g, WP and SP in a mixed breakfast meal may provide similar benefits on suppressing subsequent energy intake through increased satiety, which has an important implication for aiding in weight management [4]. Moreover, adults who prefer plant-based sources of protein may find an adequate alternative in SP that may confer comparable effects on increasing fullness to those of WP. Furthermore, the appetite-suppressing effects of both proteins when consumed as a mixed breakfast meal may have important weight loss implications, particularly when postprandial energy expenditure (thermogenesis) is increased.

It is well documented that the energy cost of digesting and metabolizing proteins (~23%) is greater than that for CHO (~6%) [6]. In the present study, postprandial thermogenesis rose to significantly higher levels and was sustained for 3 h postmeal after consumption of WP and SP, whereas CHO consumption led to a more modest rise and returned to baseline at 3 h after the meal. In addition, the higher postprandial thermogenesis after consumption of WP and SP corresponded with higher satiety sensations compared with CHO. This observation is consistent with that of Crovetti et al. [30], who reported higher postprandial thermogenesis during a 7-h period after a meal after consumption of a high-protein meal compared with a high-CHO meal.

Furthermore, there were no differences observed in postprandial thermogenesis between WP and SP, which is consistent with findings reported by Tan et al. [8], who found no difference in postprandial thermogenesis after consumption of dairy and SP sources. In contrast, some studies have reported differences in the thermogenic effect of different protein sources [6,11,35]. For example, Alfenas et al. [11] observed a higher thermogenic effect after SP compared with WP, whereas Acheson et al. [6] found that WP elicited a greater thermic response than SP. These conflicting results may be attributed to the protein content and characteristics of the meal and the length of supplement consumption. In addition, in the present study, a significantly lower RER was observed after WP and SP compared with CHO, with no significant differences between WP and SP. Although Alfenas et al. [11] previously reported a lower RER ($P < 0.027$) after consumption of WP compared with SP and CHO, the current results suggest that consumption of either WP or SP mixed into a liquid breakfast meal could lead to a similar and greater increase in fat oxidation compared with consumption of CHO. Thus, combined with increased satiety, lower energy intake and greater fat oxidation may translate into promoting negative energy balance, decreases in body fat, and increases in weight loss by using fat stores as an energy source.

The taste perception ratings of the three breakfast meals showed no significant differences, although there was a trend for WP and SP to be more "liked" than CHO. In line with findings from Acheson et al. [6], this apparent preference may have influenced the slightly higher satiety ratings observed after WP and SP compared with CHO. It has been reported that food palatability enhances meal thermogenesis, which is concomitant with the current finding that the similar palatability ratings led to similar postprandial thermogenesis after WP and SP meal consumption [36,37].

When interpreting the results of the present study, certain limitations should be considered. First, the fact that breakfast was consumed as a liquid meal rather than as a more familiar solid meal may have affected participant appetite ratings because of the potential inhibition of cognitive and sensory stimuli that normally hinder the desire to eat until consuming a habitual solid meal [38]. However, consumption of high sugary smoothies is on the rise [39], (IBISWorld's Industry Market Research), therefore this can be used as a healthy alternative option when time is limited instead of skipping breakfast. Second, the macronutrient composition varied slightly between the three breakfast meals in order to match for caloric content, appearance, taste, and texture. However, macronutrients are rarely consumed in isolation; therefore, we chose commonly consumed and palatable food that can be easily prepared and consumed on the go. In addition, greater dose of SP was used, which may have affected the ability to detect the absence of difference between two protein sources. Protein digestibility may be comparable between the two sources, yet amino acids from soy are more readily converted to urea and have higher oxidation rates compared with whey [40]. Thus, higher doses may be needed to account for that. Although the low number of male participants may have limited our ability to detect sex differences, we believe that the results of the present study are likely to benefit both sexes. Finally, the current short-term study design did not allow for accurate prediction of whether the acute subjective appetite ratings would remain the same or lead to differences in energy intake over a long-term period.

The results of the current study have important implications for current public health literature. Owing to adverse health effects of skipping breakfast, a mixed liquid breakfast meal (smoothie) with an addition of soy could be an alternative option for individuals who can't tolerate dairy or are looking to adopt a plant-based diet. Vegetarian diets based on plant-derived foods are suggested to be advantageous over animal-based foods owing to greater health benefits, less environmental burden, and a lower cost of food production [40]. In addition, there is an increasing interest in using plant-based protein sources, specifically SP, in clinical feeding diets in an effort to treat and prevent obesity [40].

The current study supports the use of liquid breakfast meals with WP and SP as a mean of reducing hunger and suppressing energy intake in the short term (3 h after ingestion). However, studies determining the long-term effects and the most appropriate timing of protein supplementation deserve attention [15,20]. In addition, current literature is inconsistent regarding the influence of food form (solid versus liquid) when comparing the satiating effects of different protein sources and therefore warrants further investigation [20,24,41].

Conclusion

The present study demonstrated that not only do protein-rich meals have greater satiating and thermic effects than do isocaloric, high-CHO meals, but also that there were no major differences in these effects between WP and SP. Both protein breakfast meals significantly reduced energy intake at lunch compared with CHO, with no differences observed, in this regard, between WP and SP. Therefore, consumption of 50 g of SP mixed into a liquid breakfast meal (smoothie) can be used as an effective nutritional strategy to aid in the management or improvement of weight in adults.

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