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Soy milk induces higher postprandial satiety than cow's milk: a cross-over experiment in healthy normal female adults

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Abstract

The differential impact of plant-based versus animal-based proteins on satiety has been a topic of interest in recent years. This paper aimed to compare the effects of soy milk, a plant-based protein source, and cow's milk, an animal-based protein source, on short-term satiety. A crossover, single-blinded study was conducted involving twenty-eight healthy Indonesian females (BMI between 18 and 25 kg/m^2, aged 19 to 21 years). Both test diets consisted of 200 mL of either soy milk (SM) or cow's milk (CM), both isovolumetric, isocaloric, and isomacronutrient (220 kcal, protein 20% En). Participants fasted overnight before diet administration and Visual Analogue Scale (VAS) questionnaires were used to assess perceived satiety. After 3 hrs of milk ingestion, an ad-libitum lunch was provided to evaluate prospective food consumption (PFC). Analysis of variance (ANOVA) repeated measures and paired T-tests or Wilcoxon were employed to compare perceived satiety and PFC. No significant differences were observed in all VAS scores. However, the area under the curve score for perceived PFC was significantly lower in the SM group (SM = 129.7±7 mm*mins; CM = 138.9±8 mm*mins). The PFC was slightly lower in the SM group than in the CM group, but the difference was not significant (337.9±16.5 kcal vs. 367±26.71 kcal). Only the SM group showed a more sustained fullness which lasted until t = 180. This present study suggested that compared to CM, SM has a higher short-term satiety effect. The higher fiber content in SM, which is known to increase satiety, might be a factor that contributed to this present finding. This evidence provided crucial information regarding the potential of SM to prevent weight gain by promoting short-term satiety sensation. The factor that may contribute to this finding could be the higher fiber content in SM, which has been shown to promote satiety and reduce insulin response. Future studies should investigate this underlying mechanism by incorporating fiber content analysis and exploring the relationship between fiber intake, insulin response, and satiety. Long-term studies are also required to determine the sustained effects of soy milk on weight management and weight loss.

1. Introduction

Obesity, a condition in which fat accumulation in the body exceeds the normal limit, is considered one of the major factors contributing to non-communicable diseases such as cancer, diabetes mellitus, and heart disease. The prevalence of obesity has risen dramatically in recent decades. Worldwide, the number of people with obesity has increased almost threefold since 1975 (World Health Organization (WHO), 2021). It is estimated that in 2030, the global prevalence of obesity (BMI ≥30 kg/m^2) will increase by 33%, accounting for 1 billion adults. WHO reported that the global proportion of obesity in adult females is higher than in males (World Obesity Federation, 2022). It is notable that among other world regions, Asia and Africa have experienced the fastest increase in overweight and obesity (Jackson *et al.,* 2020).

Diet modification has been shown to effectively prevent obesity (DiNicolantonio *et al.,* 2018; D'Innocenzo *et al.,* 2019). Several studies suggested that ingestion of food with high satiety properties may reduce subsequent food intake (Paddon-Jones *et al*., 2008; Westerterp-Plantenga *et al.,* 2012). Satiety is a process that prevents further eating by decreasing hunger and increasing fullness after meal ingestion (Rebello *et al.,* 2013). Satiety involves complex interactions between gut hormones and the brain. After a meal is digested and

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absorbed in the gastrointestinal tract, several hormonal signals are released into the brain and stimulate satiety. Leptin, ghrelin, cholecystokinin (CCK), insulin, and Peptide-YY are suggested to have interactions with the brain to regulate food intake (Benelam, 2009). In addition, sensory and cognitive aspects of food also play roles in the satiety stimulation of the brain (Rebello *et al.,* 2013).

It has been well demonstrated that compared to other macronutrients, protein has the highest satiety effect (Poppitt *et al.,* 1998; Long *et al.,* 2000). Protein ingestion results in CCK secretion which in turn stimulates the lateral medulla of the hypothalamus, an area that is involved in reward behavior and satiety regulation. CCK also plays a role in gastric motility inhibition, pancreatic secretion stimulation, and gall bladder contraction (Austin and Marks, 2008).

Recently, researchers attempted to investigate the effect of different protein sources on satiety and weight loss. Limited human studies investigating the effect of protein sources on satiety remained providing inconsistent results. However, when it comes to weight loss intervention, a plant protein-based diet was preferred more than animal-based protein. It has been suggested that a high-protein diet based on soy lowered total blood cholesterol and LDL cholesterol more than a high-protein meat-based diet did after 14 days of intervention (Neacsu *et al*., 2014).

This present study aimed to compare the effect of plant- vs animal-based protein on short-term satiety. The soy milk was used to correspond plant-based protein whereas cow's milk represented animal-based protein. Soy milk is interesting to investigate since it has been widely consumed as an alternative milk, especially in the Asian population (Arwanto *et al*., 2022).

2. Materials and methods

2.1 Study design

A total of twenty-eight healthy and lean female adults (BMI 18-25 kg/m^2) volunteered in this present randomized crossover study (Figure 1). The volunteer's ages ranged from 19-21 years old. The volunteers were blinded to the manipulation and the order of the test food given. However, upon recruitment, they all were informed to consume soy and cow milk products. The respondents whose either cow's milk or soy allergies were not allowed to participate in this study. Written informed consent was administered to the participants.

2.2 Protocols

The protocol was a crossover design with two arms (soy vs cow's milk). Soy milk (SM) and cow's milk (CM) correspond to plant and animal protein diets respectively. On day 1, all participants were requested to arrive at the laboratory at 7.45 AM. After a 10-minute rest, participants were asked to fill out the Visual Analogue Scale (VAS) questionnaire to assess the subjective hunger, desire to eat, and satiety sensation as the baseline measurement. Then at 08.00 AM, the participants were randomly assigned to receive either SM or CM, with a portion of a sandwich as breakfast. Before the experiment day, the volunteers were requested to fast overnight (8 h). The VAS questionnaire administration was repeated at 30, 60, 90, 120, 150, and 180 mins. After 3 hrs of the test meal, the participants were served an *ad libitum* high-fat diet as lunch. They were requested to consume lunch as much as they wanted. The lunch was weighed with digital kitchen scales for its before and after consumption to calculate the energy intake of the subsequent diet in each participant. After a seven-day washout period, the participant conducted a similar protocol except for the preload test that was switched, depending on the preload test they received on day 1. The protocol diagram can be seen in Figure 2. The protocol was approved by the

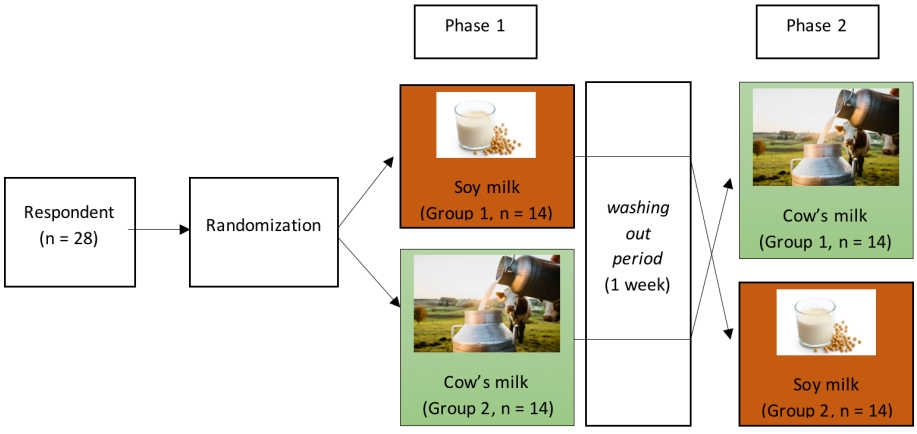

Figure 1. Illustration of study design. A total of 28 female respondents volunteered in this study. The participants were randomly assigned to either the soy milk group (group 1) or the cow's milk group (group 2). After a week-long washout period, the groups were crossed over. Throughout the study, participants were kept blinded to which group they belonged to.

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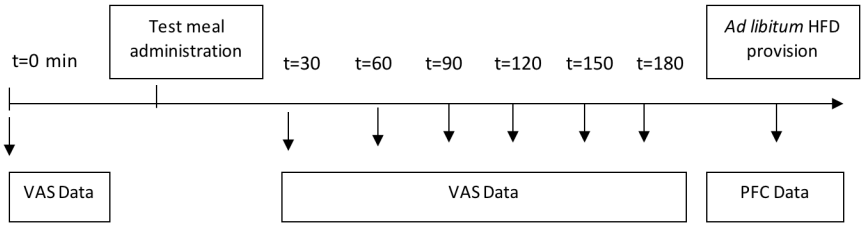

Figure 2. Illustration of the study's schematic protocol. After fasting overnight prior to the intervention day, the respondent was asked to complete a Visual Analogue Scale (VAS) questionnaire at t = 0 as a baseline. VAS questionnaires were also administered at 30, 60, 90, 120, 150, and 180 mins after consuming the test meal. After 3 hrs of the test meal ingestion, a high-fat diet (HFD) lunch was provided ad libitum, and Prospective Food Consumption (PFC) data was obtained from the lunch intake.

Health Research Ethics Committee of the Public Health Faculty, Universitas Airlangga No: 95/EA/KEPK/2023.

2.3 Test meals

250 ml of soy milk (SM) and cow's milk (CM) were given as the test meals. To ensure that the participants were not aware of the color and taste of the test meals, chocolate powder was added to the milk liquid. Soy milk was made by dissolving 55 g of commercial soy powder with 250 mL of water and homogenized by using a blender. Cow's milk was made by dissolving 50 g of commercial powder with water. The test meals were similar in their energy and macronutrient contents as depicted in Table 1.

Table 1. Energy and macronutrient compositions of test meals.

	Soy milk	Cow's milk
Energy (kcal)	220	220
Protein (g, En%)	11 (20%)	11 (20%)
Fat (g, En%)	6 (24%)	6.9 (28%)
Carbohydrate (g, En%)	31 (56%)	28.9 (52%)

The test meals were served together with a sandwich, containing 240 kcal, to provide a standard energy contribution for breakfast. Thus, the test meal and the sandwich contributed to 460 kcal (20.4% of the total Daily Energy Requirement for Indonesian people aged 19-29).

2.4 Ad libitum meal

The lunch meal was based on fried noodles, sunny upside chicken eggs, and meatballs. The lunch meal consisted of 402 kcal energy per 100 g. Fat content in the lunch meal is 44% of the total energy. The energy and fat calculations were done using Nutrisurvey software according to the meal recipe.

2.5 Data collection

Respondents' perceived hunger, fullness, and desire to eat as the subjective satiety data as well as the energy intake of subsequent diet to assess the satiety of the test meals were collected. The subjective hunger, fullness, and desire to eat ratings were measured using self-reported Visual Analogue Scales (VASs) at min 0 (baseline), 30, 60, 90, 120, 150, and 180. The scale ranged from "not hungry at all" to "extremely hungry". The energy intake of the ad libitum lunch by calculating the amount of lunch that was consumed by the participants was also calculated.

2.6 Data analysis

Subjective hunger, desire to eat, and satiety sensation were analyzed using ANOVA repeated measures and included a time-meal interaction. Area Under the Curve (AUC) for the subjective data was calculated by using the trapezoid rule (Wolever *et al*., 1991). To assess whether there were any significant differences in the AUCs between the test meals, a paired *t-test* was performed for the normal data. Furthermore, the energy intakes between the test meals were compared using a paired *t-test.* A Wilcoxon test would be performed if the data was not normally distributed. The p-value of <0.05 was considered as significant. All statistics were performed using Graph Pad Prism software.

3. Results

This present study aims to investigate the effects of plant- and animal-based protein on postprandial satiety. To achieve this objective, the perceived hunger, fullness, and desire to eat as well as the energy from the Prospective Food Consumption (PFC) of volunteers after consuming soy- and cow's milk were compared.

3.1 Perceived hunger

The VAS scores across time and AUC response for perceived hunger are presented in Figure 3. Time ($F(2.174, 117.4) = 46.90$, $p<0.0001$) but not treatment ($F(1, 54) = 0.3434$, $p>0.05$) had a significant effect on VAS scores. No significant difference was found in the post-prandial VAS score for perceived hunger between the SM and the CM groups. There was a significant effect for the time ($p<0.0001$) but not with the treatment ($p>0.05$) on hunger. A noteworthy finding emerged from this present research: although the initial VAS score at baseline (t = 0) was slightly higher in the SM group

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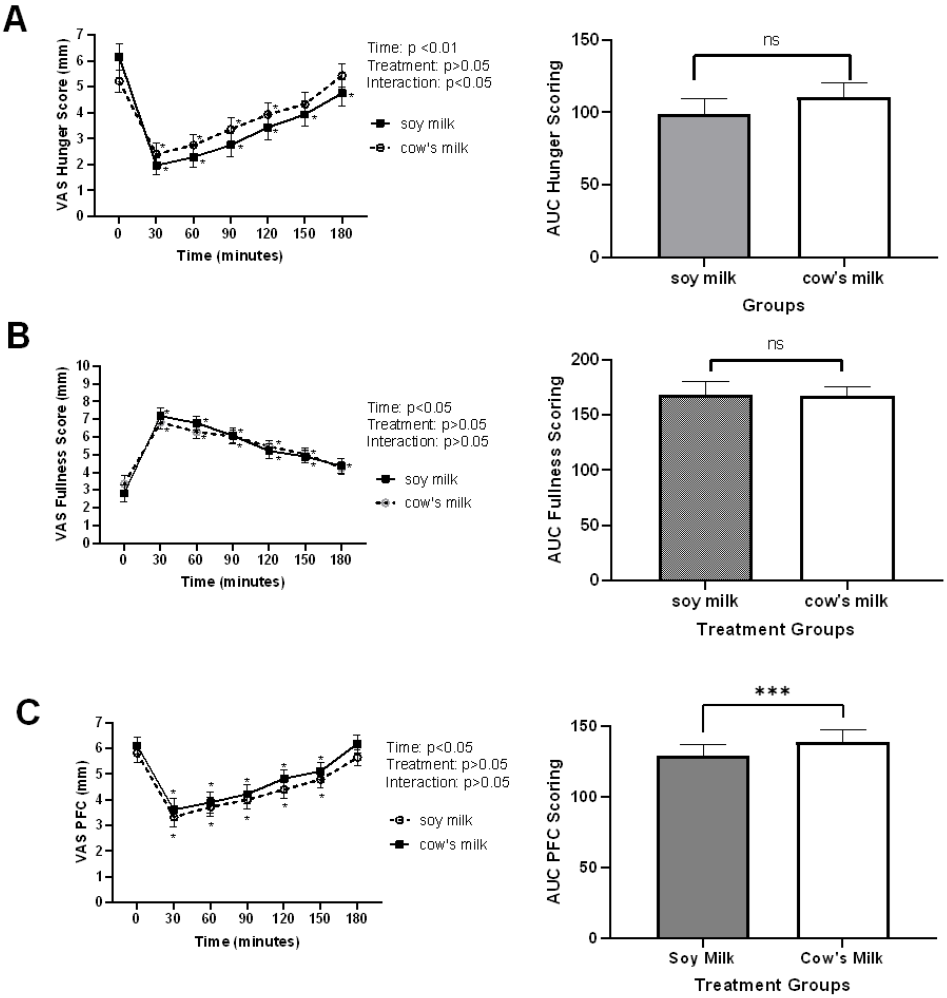

Figure 3. Comparison of A: Perceived Hunger between soy- and cow's milk (left) and the AUC of Hunger (right). B: Perceived Fullness between soy- and cow's milk (left) and the AUC of Fullness (right). C: Perceived PFC between soy- and cow's milk (left) and the AUC of Desire to Eat (right). Asterix mark (*) at the curves corresponding to a significant difference (<0.05) of a particular time point perceived scale compared to baseline (t = 0) within the experiment group.

compared to the CM group (6.14 mm vs.5.21 mm, p-value>0.05), the SM group consistently displayed lower VAS scores at t = 30, and this trend persisted until t = 180. In other words, despite their initial higher hunger, the SM group experienced a greater reduction in hunger compared to the CM group. The study found that after 30 mins of consuming a test meal, both groups reported gradually increasing feelings of hunger until t = 180, as measured by VAS scores. However, the SM group consistently reported lower levels of perceived hunger at all post-prandial time points compared to the CM group. The differences in perceived hunger between the two groups were significant at all post-prandial time points for the SM group, while for the CM group, these differences were only observed at specific time points (at t = 30, 60, 90, and 120). At the end of the study (t = 180), the perceived hunger VAS score for the CM group was similar to the baseline score, whereas the SM group continued to report lower levels of perceived hunger. The study also found that the AUC (area under the curve) for perceived hunger was lower in the SM group compared to the CM group, indicating that the SM group experienced a lower overall level of perceived hunger during the study period.

3.2 Perceived fullness

Time (F (2.497, 134.8) = 54.13, p<0.0001), but not treatment (F (1, 54) = 0.00, p>0.05), had a significant effect on the VAS score for fullness. Both groups reported significantly lower fullness VAS scores at t = 30, 60, 90, 120, and 150 compared to the baseline (t = 0). The difference in fullness VAS scores remained significant in the SM group at t = 180. The perceived fullness AUCs between the SM and the CM groups were similar and did not have a significant difference (168.7±11.2 vs. 167.2±8.73 mm*min).

3.3 Perceived prospective food consumption

The VAS scores for satiety also showed a significant effect of time (F (2.7111, 146.4) = 43.49, p<0.0001), but not treatment (F (1, 54) = 0.5748, p>0.05). Both groups displayed a decrease in satiety VAS scores at t = 30, followed by a gradual increase until t = 180. Compared to the baseline (t = 0), the two protein groups showed significantly lower VAS scores at all time points, but not at t = 180. The satiety VAS scores at all post-prandial time points were significantly lower than the baseline (t = 0) for both groups. However, at t = 180, the satiety

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VAS score of the CM group was almost similar to the baseline score (5.7 mm vs 6.2 mm) whereas the SM group continued to report lower levels of satiety. The study found no significant difference in the AUC for satiety between the SM and CM groups (337.9±16.5 kcal vs. 367±26.71, $p<0.001$).

3.4 Energy from prospective food consumption

As depicted in Figure 4, after 3 hrs of test-meal ingestion, the volunteers were provided with an *ad libitum* high-fat diet (402 kcal/ 100 g, En% fat = 44%). The results showed that the SM group consumed less energy from this subsequent meal compared to the CM group, but the difference was not statistically significant. The energy intakes in the SM and the CM groups were 337.9±16.5 kcal and 367±26.71 kcal respectively.

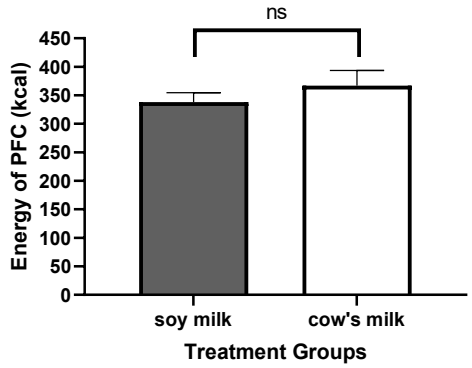

Figure 4. Comparison of the energy intakes from *ad libitum* Prospective Food Consumption after 3 hrs soy- and cow's milk ingestion.

4. Discussion

Although it is widely known that protein has a more significant satiating effect than fat and carbohydrates, the impact of different protein sources on short-term satiety is still inconclusive. This present study aimed to investigate the influence of plant- and animal-based proteins on short-term satiety in normal healthy adult females. To answer the research question, soy milk (SM) and cow's milk (CM) as the representatives of plant- and animal-based protein were used. Both beverages contained high protein (11 g, 20 En%), isocaloric (220 kcal), and isovolumetric (250 mL), and were similar in the macronutrient content, except for the carbohydrate that was a little higher in the SM (31 g vs. 28.9 g). After 3 hrs of protein ingestion, the respondents were asked to consume *ad libitum* lunch based on noodles, eggs, and meatballs which was a common traditional local lunch meal in Indonesia.

This study was in agreement with a previous study by Kristensen *et al*. (2016), who found that plant-based proteins have a greater effect on satiety compared to animal-based proteins. This present study specifically compared a plant-based protein (SM) to an animal-based protein (CM) in normal adult females and found that SM had a superior effect on satiety feeling. The Kristensen *et al*. (2016) study compared patties made from fava beans and legumes to animal-based patties made from veal and pork, and found that the legume-based patties, regardless of their protein content, induced higher satiety ratings and lower postprandial energy intakes than the animal-based patties. These findings suggest that incorporating more plant-based proteins into the diets may have potential benefits for weight management.

The possible underlying reason for the greater satiety promotion by the plant-based protein might be due to its fiber content. Plant-based meals naturally are rich in fiber. The fiber content in soy is approximately as much as 9% of the dry weight (Qin *et al.,* 2022). It is suggested that a small difference in the fiber amount (about 8 g) could lead to a significant increase in satiety by lowering the insulin response (Mathern *et al.,* 2009).

The insulin response and satiety mechanism are interconnected in the context of fiber intake. When consuming foods rich in fiber, such as plant-based proteins, it takes longer for the stomach to empty due to the increased bulk. This slow digestion leads to a gradual release of glucose into the bloodstream, which results in a lower and more sustained insulin response compared to foods with rapid digestion and spike in blood sugar levels (Shkembi and Huppertz, 2023). The lower insulin response has been shown to promote feelings of satiety or fullness, as insulin is also involved in signaling the brain to stop eating. Therefore, a small difference in fiber content, as seen in plant-based proteins, could lead to a significant increase in satiety by lowering the insulin response. In this present study, fiber content analysis from the SM is not incorporated and thus limits further explanation of that mechanism. However, future studies should consider measuring fiber content to further elucidate the potential role of fiber in greater satiety promotion by a plant-based diet.

The second important finding in this study was that the SM may have a prolonged satiety sensation. The ingestion of SM could significantly maintain the satiety sensation even at 3 hrs postprandial. In contrast, the CM ingestion led to shorter satiety feelings and its effect was mostly diminished at 150 mins postprandial. Also, in one of the subjective parameters, it was found that the 3 hrs of postprandial satiety feeling resulting from CM was similar to the pre-breakfast condition. It is unclear regarding the more sustained effect of SM on satiety. Prior studies confirmed that SM caused more rapid gastrointestinal transit time than CM, therefore SM was referred to as a 'fast protein' while CM was a 'slow

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protein' (Bos *et al.,* 2002). Also, the glycaemic index of CM (GI = 45) was suggested to be slightly lower compared to SM (GI = 48) (Shkembi and Huppertz, 2023).

Whilst this present study showed that the plant protein induced a higher satiety effect compared to the animal protein, this result was not in agreement with the majority of previous studies. Previously, it was examined that plant protein had a lower effect on satiety (Arslan *et al.,* 2023) whereas others mentioned no difference was found between plant- and animal-based protein (Neacsu *et al.,* 2014; Douglas *et al.,* 2015; Medawar *et al*., 2023). The discrepancy in findings might be attributed to differences in the protein type, dose, diet form, and macronutrient contents (Muliadi *et al.*, 2022). Veldhorst *et al.* (2009) reported that the differences in amino acid blood concentration and satiety parameters resulting from whey, casein, and soy could be observed when the protein was given at the level of 10% of the total energy but not at the level of 25% or higher. Güldemir *et al.* (2022) suggested that cow's milk was more satiating than soy milk when given with a sandwich, possibly due to the different macronutrient composition. In that study, the protein content of the cow's milk was higher compared to the soy milk, which was 10.6 g and 7 g respectively. Additionally, the type of protein used can lead to different results. Douglas *et al*. (2015) reported that beef was more satiating than soy when used as a mixed dish with isoenergetic and isomacronutrient properties. However, when a combination of proteins was used, different results were observed as well. Arslan *et al.* (2023) applied the different sources of protein in omelets in their study. The animal-based omelette was made from a mixture of cow's milk and whole egg, while the other omelette was based on chickpea and soy milk. Both omelettes have similar content in energy and macronutrient content. The study shows that the omelette from vegetables had lower satiety than the animal-origin omelette.

The strength of this present study lies in the matched volume, macronutrient, and energy between soy milk (SM) and cow's milk (CM), which allowed for highlighting the effect of different protein sources on satiety while minimizing other potential effects. The use of soy milk as a representative of plant-based protein is significant, as soy is a popular dietary plant protein in several Asian countries, including China, Japan, South Korea, and Indonesia, where it accounts for 10-15.3% of the protein intake (Messina *et al.,* 2006). Nevertheless, the limitation of this present study was the absence of hormonal biomarker assessment that could provide a more comprehensive understanding of the results. Also, although the subsequent energy intake was higher after the CM consumption, the difference was not statistically significant. The use of liquid instead of solid form of diet has been suggested to elicit blunted satiety and subsequent energy intakes (Stull *et al.,* 2008).

Conflict of interest

The authors declare no conflict of interest.

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