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SATIETY OF SELECTED INDIAN FOODS IS INFLUENCED MORE BY THE PROTEIN AND FAT THAN THE CARBOHYDRATE CONTENT

Meeta Raheja PhD, Former Research Scholar, Department of Food Science and Nutrition, SNDT Women's University; Presently Head - BU Food, Rettenmaier India Pvt. Ltd.

Shobha A. Udipi* PhD, Research Head and Director, Hon Director, Integrative Nutrition and Ayurceuticals; Former Professor and Head, Department of Food Science and Nutrition, SNDT Women's University. *Corresponding Author

ABSTRACT With the rising prevalence of overweight and obesity, helping people control/ manage their energy intake is important. Foods/ recipes that can confer satiety would help in this regard. Each of the macronutrients has different effects on satiety, with protein conferring greater satiety. In the present study, nine common Indian equicaloric recipes that varied in their macronutrient composition were tested for their satiety. Standard recipes for these were prepared providing approximately 15% energy from protein, 20% from fat and about 40% from carbohydrates. In the test recipes, either energy contribution from protein was raised to 30%, or fat contributed about 40% with carbohydrates, giving about 48% energy. In the high carbohydrate versions, carbohydrate recipes provided about 80% energy while fat provided only 6% energy. Satiety was assessed with 35-47 participants and satiety scores were calculated by area under the curve. Satiety scores were positively correlated with protein and fibre content but were negatively correlated with fat. There was no correlation between carbohydrate content and satiety scores. High protein variations had higher cooked weights, tended to have lower energy density and delayed hunger for a longer period. The mixture of dairy and plant protein sources gave greater satiety than did plant sources and dairy sources alone gave the lowest satiety. Also, sweet recipes were rated lower than savoury ones. It would be worthwhile to examine the effect of different sources of plant proteins with and without dairy proteins as the latter appeared to be less satiating than plant proteins.

KEYWORDS : Satiety, plant proteins, energy density, cooked weight, portion size, mixed foods

INTRODUCTION

The rising prevalence of overweight and obesity has necessitated a focus on strategies by which energy intake can be reduced without compromising satiety. However, the satiety of reduced-calorie diets is of concern, because while reducing the energy content, often bulk decreases. Foods that are palatable/ attractive and well-liked, tend to have lower bulk and satiety. Thus, individuals on weight loss regimes may consume more food in amount and/or frequency, thus compromising the possible accruable benefits.

Increasing the satiating properties of foods may aid in efforts aimed at weight loss and/or maintenance. Among the macronutrients, protein has been shown to be more satiating (Westerterp-Plantenga, Lemmens, Westerterp, 2012). However, many studies have used single protein sources e.g. whey protein, and egg albumin. Not many have compared the macronutrients using typical foods, especially using vegetarian food sources, particularly in the Indian context. Also, most studies have used fairly high amounts of protein contributing a fairly high percentage of the energy intake, even up to 60% of the energy. Not all commonly consumed Indian recipes contain such high amounts of protein, especially in Indian cuisines. Therefore, the present study examined the effects of manipulating the content of the three macronutrients on satiety in the short term. The contribution of protein was restricted to 30% of total energy. Nine recipes i.e. three main meal items, two desserts and four snacks/breakfast items that are commonly consumed in India were tested. Additionally, the influence of factors such as palatability, weight or volume, energy density and portion size on satiety conferred by these nine recipes was observed (Tey et al., 2018).

METHODOLOGY

The study was approved by the Intersystems Biomedica Ethics Committee.

Selection of Subjects: Fifty-one female graduate students aged 20-30 years from SNDT Women's University were recruited after obtaining informed written consent. Some subjects dropped out of the study and the number of subjects was 37 to 45 participants for different test recipes.

Inclusion and Exclusion criteria: Healthy females who did not have any minor illness in the previous two weeks or any major illness in the previous 3 months, those who were obese (BMI ≥30), or on medication/oral contraceptives and had food allergies were excluded.

All 51 subjects were assessed for eating behaviour using the 3-factor eating questionnaire designed by Stunkard and Messick (1985), to measure cognitive restraint of eating (Factor 1), disinhibition (Factor 2) and hunger (Factor 3).

Study Design:

A within-subjects, repeated measures design was used. This study was modelled on the lines of the study by Holt et al., (1995), wherein each subject acted as her own control, and was tested at the same time of day, under similar conditions. Each of the nine recipes had four variations differing in per cent energy from protein, fat and carbohydrate (CHO) (Table 1).

Table 1: Percent Energy Contributed by Protein, Fat and Carbohydrate

Test Recipe	Per cent Energy Contribution from		
	Protein	Fat	Carbohydrate (CHO)
Standard	14.8±0.5[1] 14.0-15.5[2]	20.1±0.5 19.1-20.6	65.0±0.5 64.2-65.7
High Protein	29.6±0.4 29.1-30.4	11.6±5.9 5.5-7.4 (n=5) or 17.2-18.3(n=4)	58.2±6.5 62.3-64.6(n=5) or 49.0-53.4(n=4)
High Fat	10.8±0.9 10.0-11.7	40.1±0.4 39.6-40.7	48.6±1.5 46.3-51.3
High Carbohydrate	8.8±0.4 8.0-9.3	6.6±0.4 6.0-7.2	84.4±0.3 84.0-84.9

[1]Mean±SD, [2]Minimum-Maximum

The nine test recipes (sago *kheer*, vegetable cutlets, *masala* rice, *missi roti*, sandwich, *poha*, stuffed *baati*, vermicelli *upma* and fruit custard) were compared with white bread. Equicaloric portions (250 kcal/portion) of the reference food i.e., white bread and the test recipes were administered on separate days.

Test Recipes: Each recipe was standardized to ensure constant cooked weight and volume and prepared in the Nutrition Laboratory. Protein content was increased in seven high protein test foods using soy chunks/soy granules in seven recipes, except in *kheer* and fruit custard, for which skimmed milk powder was used to increase the protein and for vermicelli *upma*, both soy granules and skim milk powder were used. Fat content was increased by using oil and groundnut. CHO content was increased by using sugar/arrowroot flour.

Protocol: Subjects were asked not to deviate from their regular physical activity and meal patterns on the day before each test. Each subject maintained a detailed record of food intake and activity patterns for 24 hours before every test session. Subjects were asked to report to the laboratory after an overnight fast (>10 hours) on the morning of each test.

White bread was tested first. The test foods were administered in random order to batches of 8 to 10 subjects. In the laboratory, subjects were seated 3 feet apart to minimize interaction. After rating their fasting hunger on the hunger rating scale (Holt et al., 1995), each subject was provided the test food with 250 ml of water at '0' time. The test recipe was placed in a cardboard box with a large enough window to allow the subject to pick the food but to minimize pre-conception about the hedonic and satiating properties of the foods. Sago *kheer* and fruit custard were presented in bowls.

Subjects were instructed to consume the entire portion within 15 minutes and were free to drink the water provided. The time taken to consume the food and its palatability were rated immediately after consumption. They were asked to indicate prospective consumption using the visual analogue scale (VAS). Thereafter, subjects were not permitted to eat or drink until the end of the test session. They were permitted to read or listen to music but were not allowed to talk to each other. From '0' to 120 minutes, subjects marked their level of hunger after 15-minute intervals, using a 7-point scale, ranging from -3 (extremely hungry) to +3 (extremely satisfied). After 120 minutes, subjects were allowed to leave the laboratory and were free to consume any food(s) of their choice. They were required to maintain a detailed record of all foods and beverages as well as physical activity for the rest of the day.

Anthropometric measurements: Before starting the test sessions, the height and weight of each subject were measured using standardized methods and body mass index (BMI) was calculated. Height was noted in centimetres to the nearest millimetre. Weight was recorded to the nearest 500g using a spring balance (Eagle Co). Measurements were taken three times and the average was calculated. Body mass index was calculated.

Satiety Index Scores: Satiety index (SI) was calculated by the method of Holt et al., (1995). The satiety response to each food was quantified as the incremental area under the 120-minute response curve (AUC).

Any negative area was ignored. SI score (%) was calculated as follows:

$$SI (\%) = \frac{\text{Area under 120 min satiety curve for 250 kcal of test food}}{\text{Group average area under 120 min satiety curve for 250 kcal of reference food}} \times 100$$

Statistical Analysis: Data was analyzed using the SPSS Windows software version 16.0. Means and standard deviations were computed. Karl Pearson's correlation, analysis of variance and t-test were applied.

RESULTS

Profile Of Subjects: The mean age of the subjects was 22.2±1.8 years (minimum 20 years, maximum 27 years). The mean height was 158.0±5.2 cm (minimum 141.0, maximum 177.0 cm) and the mean weight was 53.1±8.0 kg (minimum 36.0, maximum 72 kg). The mean BMI was 21.0±2.8 kg/m^2 (minimum 16, maximum 28.9). None except one subject was obese as per the World Health Organization (WHO) criteria (2004). The mean scores for the three factors (Stunkard and Messick, 1985) were: Factor 1 (cognitive restraint of eating) – 8.8±4.9 and no subject had a score >10.5 indicating that all subjects had normal eating behaviour. The subjects' degree of disinhibition was low as the mean score for Factor 2 was 3.7±1.9, well within the maximum possible score of 16. The mean score for Factor 3 was 4.7±1.8, much lower than the maximum possible score of 14.

Satiety Index Scores: Mean SI scores of the standard test recipes as a percentage of the SI for the reference food bread varied between 90% and 137.5% (F=2.378, p=0.008) (Table 2). The SI score for fruit custard was the lowest and the post-hoc Bonferroni test indicated a significant difference between SI scores for fruit custard and *missi roti*. SI scores for the high protein variations of eight of the nine test recipes were significantly higher than their respective standards and differed significantly from each other (F=2.194, p=0.027). Among the high-fat variations, eight of the nine recipes had lower SI scores than the standard, with significant differences between the recipes (F=2.011, p=0.044). Among the high CHO variations, four recipes had higher scores than the standards, but five had lower scores. There was no significant difference between the high CHO test recipes (F=1.054, p=0.395). The per cent difference between SI scores in the standard recipes and the high-protein, high-fat, high CHO variations was calculated (Table 2). Overall, the high protein variations conferred 1.3 times the satiety conferred by the standard recipes. Whereas the mean difference between standard and high-fat recipes was negative suggesting that high-fat recipes were comparatively less satiating. In cutlet, *masala* rice, *missi roti*, sandwich, poha and stuffed *baati*, soy granules/chunks were used to increase the protein content, in *kheer* and fruit custard milk powder was used, whereas in vermicelli *upma*, both were used. Significant differences were observed in the SI scores of the test recipes containing animal (dairy) protein (120.1±72.6), and those containing plant protein (132.1±67.7), whereas those containing a combination of plant and animal protein had the highest mean scores (142.5±68.3). Post-hoc Bonferroni test indicated that the latter had a significantly higher mean score than the recipes containing dairy protein alone.

Table 2: SI Scores (%) of the Different Variations of Test Foods and Mean Percent Difference between Standard Recipes and SI Scores of High Protein, High Fat, High CHO Variations

Test Food	Standard	High Protein	High Fat	High CHO
SI Scores (%) Mean ± SD				
Sago Kheer	103.5±48.0	120.4±64.3	93.9±53.0	102.4±52.7
Vegetable Cutlet	105.4±54.4	117.0±61.7	96.9±60.6	133.3±56.6
Masala Rice	122.1±60.9	149.3±69.6	114.3±56.3	132.4±62.9
Missi Roti	135.2±70.3	128.8±69.7	111.4±64.6	117.6±68.9
Sandwich	94.6±62.8	133.4±51.7	91.5±58.7	115.8±56.6
Poha	120.7±57.2	144.1±66.7	106.0±46.8	117.9±51.3
Stuffed Baati	120.0±65.3	127.9±59.4	108.2±48.6	99.8±50.1
Vermicelli Upma	137.5±62.5	155.6±61.9	122.3±52.8	113.4±61.2
Fruits with Custard	90.0±54.0	119.8±67.0	103.4±64.7	128.7±62.9
Mean Percent Difference in SI Scores between Standard and Test Recipes				
Sago Kheer	-	+30.8	-9.0	20.9
Vegetable Cutlet	-	+5.6	-3.7	48.7
Masala Rice	-	+21.9	-3.2	+8.2
Missi Roti	-	-0.4	-18.7	-11.0
Sandwich	-	+85.2	+12.3	+46.7
Poha	-	+17.7	-13.7	-2.2
Stuffed Baati	-	+29.7	+13.1	-6.0
Vermicelli Upma	-	+18.8	-4.0	-8.3
Fruits with Custard	-	+50.0	+16.0	+59.4
Overall Mean	-	+28.3±24.3	-1.2±11.7	+16.9±27.6

Pearson's correlation coefficients were calculated between SI scores and the macronutrient composition of the foods. Significant, positive correlations were obtained between SI scores and the protein content (r = +0.547, p=0.000) and fibre content (r = +0.472, p=0.001), whereas a negative correlation was observed between the fat content and SI scores (r = - 0.401, p=0.006). There was no significant correlation with the carbohydrate content (r=0.088).

Food Attributes Influencing Satiety Scores:

Cooked Weights: Cooked weights of the foods varied from 74 g for the high-fat *missi roti* to 270 g for the high-protein *masala* rice (Table 3). High protein variations had higher cooked weights than the high fat and high CHO variations, but there was no significant difference (F=1.066, p=0.376). Cooked weight was not significantly correlated with SI scores (r = 0.252, p=-0.064), except for sago *kheer* and fruit custard which were semisolid. Their volume was significantly and positively correlated with SI scores (r = 0.752, p=0.010).

Table 3: Cooked Weights and Energy Density of the Test Recipes

Test Food	Cooked Weights				Energy Density (kcal/g)			
	STD	High Protein	High Fat	High CHO	STD	High Protein	High Fat	High CHO
Bread (Reference)	102	-	-	-	2.45	-	-	-
Sago Kheer	193	199	180	173	1.28	1.27	1.40	1.43
Vegetable Cutlet	130	145	94	140	1.88	1.74	2.67	1.80
Masala Rice	190	270	156	144	1.31	0.93	1.63	1.73
Missi Roti	86	114	74	80	2.85	2.18	3.42	3.14
Sandwich	85	112	77	84	2.89	2.22	3.26	3.01

Poha	150	195	126	170	1.65	1.31	1.95	1.49
Stuffed Baati	98	92	78	106	2.59	2.76	3.19	2.41
Vermicelli Upma	206	234	190	176	1.22	1.06	1.34	1.44
Fruits with Custard	213	209	200	251	1.16	1.22	1.25	1.00

Energy Density (ED): ED of test recipes did not differ significantly (Table 3, F=0.995, p=0.407). ED of high-protein variations was lower for 7 of the 9 test recipes, whereas high-fat and high CHO variations tended to have higher ED than the standard and high-protein test recipes. A negative but non-significant correlation was observed between ED and SI (r = -0.209, p=0.104).

Palatability: Palatability ratings varied from a negative score of -0.6 for bread to a positive score of 2.0 for the high-fat variation of the sandwich. The correlation coefficients for mean palatability ratings with SI were not significant.

Portion size: Mean VAS ratings for subjects' perception regarding portion size of each test (Table 4) showed that the reference food, bread, had the highest rating followed by the standard recipe for *missi roti*, whereas sandwich and fruit custard had the lowest ratings. High-protein variations for all except one recipe had higher mean ratings than their standard recipes. However, high-fat variations received lower ratings than the high-protein, high CHO variations. Ratings for portion sufficiency were positively and significantly correlated with the cooked weight of the test foods (r = 0.431, p=0.007)

Sensory–Specific Satiety: After eating each test food, subjects were required to answer five questions about prospective consumption using a 10 mm VAS.

(i) "*How much of this food would you like to eat (Nothing at all – A large amount)*?" Mean ratings varied from 1.1 corresponding to a very low desire to consume more of the same food to as high a value as 4.4. Overall, the high protein variations received lower ratings compared to the standard recipes as well as the high fat variations and to a large extent, the high carbohydrate variations. The desire to eat more was highly correlated with palatability ratings (r = +0.826, p=0.000) and with the SI scores (Table 5).

Table 4: Mean Ratings for Sufficiency of Portion Size for the Test Recipes and Correlation with SI Scores

Test Food	Standard		High Protein		High Fat		High CHO	
Bread (Reference)	7.0 ± 1.9[1]	0.361[2], 0.005[3]	-		-	-	-	-
Sago Kheer	5.5 ± 2.0	0.400, 0.003	5.8 ± 2.1	0.618, 0.000	5.2 ± 2.4	0.498, 0.000	6.5 ± 2.0	0.272, 0.035
Vegetable Cutlet	5.4 ± 1.7	0.140, 0.177	6.6 ± 1.9	0.302, 0.021	5.0 ± 1.7	–0.098, 0.258	6.5 ± 1.8	0.378, 0.005
Masala Rice	6.5 ± 2.1	0.478, 0.001	7.6 ± 1.9	0.496, 0.000	5.8 ± 2.0	0.526, 0.000	6.9 ± 2.0	0.514, 0.000
Missi Roti	6.8 ± 1.9	0.646, 0.000	6.3 ± 1.9	0.415, 0.005	5.7 ± 1.9	0.492, 0.001	6.4 ± 2.4	0.453, 0.002
Sandwich	4.4 ± 2.5	0.063, 0.351	5.4 ± 2.0	0.058, 0.365	4.0 ± 2.3	0.209, 0.101	5.0 ± 2.5	0.245, 0.067
Poha	6.1 ± 2.1	0.174, 0.152	7.1 ± 2.3	0.225, 0.091	5.2 ± 1.8	0.200, 0.117	6.1 ± 2.2	0.417, 0.005
Stuffed Baati	5.5 ± 1.8	0.119, 0.235	6.2 ± 2.0	0.156, 0.171	5.1 ± 1.3	0.255, 0.058	5.5 ± 1.9	0.201, 0.110
Vermicelli Upma	6.4 ± 2.4	0.551, 0.000	7.7 ± 1.9	0.290, 0.035	6.2 ± 2.1	0.384, 0.007	6.0 ± 2.0	0.269, 0.046
Fruits with Custard	4.8 ± 2.1	0.608, 0.000	6.1 ± 2.4	0.234, 0.073	5.4 ± 2.4	0.299, 0.031	6.3 ± 1.9	0.294, 0.033

[1]Mean ± SD; [2]r value; [3]p value

Table 5: Subjects' Mean Ratings for Desire to Eat More of the Same Food and Correlation of Ratings with SI Scores 'How much more of this food would you like to eat'

Test Food	Standard		High Protein		High Fat		High CHO	
Bread	1.4 ± 1.4[1]	0.098[2], 0.248[3]	–	-	–	-	–	-
Sago Kheer	3.1 ± 2.5	–0.217, 0.076	2.3 ± 2.0	–0.577, 0.000	2.7 ± 2.5	0.349, 0.009	2.2 ± 2.1	–0.269, 0.030
Vegetable Cutlet	2.9 ± 2.6	–0.062, 0.342	1.6 ± 1.8	–0.169, 0.131	3.7 ± 2.6	0.262, 0.039	1.7 ± 1.6	–0.334, 0.012
Masala Rice	4.4 ± 1.1	–0.232, 0.070	1.8 ± 2.0	–0.249, 0.056	2.9 ± 2.2	0.056, 0.362	1.1 ± 1.2	–0.165, 0.149
Missi Roti	2.2 ± 2.5	0.033, 0.423	2.3 ± 2.3	–0.049, 0.386	2.7 ± 2.1	0.281, 0.046	1.3 ± 1.7	–0.126, 0.228
Sandwich	2.9 ± 2.5	0.320, 0.023	1.8 ± 1.9	–0.068, 0.343	3.7 ± 2.8	0.036, 0.415	2.3 ± 2.5	–0.061, 0.357
Poha	2.1 ± 2.3	0.131, 0.220	1.4 ± 1.7	–0.113, 0.253	3.1 ± 2.6	0.246, 0.071	2.3 ± 2.3	0.181, 0.142
Stuffed Baati	2.3 ± 2.2	0.118, 0.237	1.7 ± 1.9	–0.041, 0.403	2.5 ± 2.2	0.027, 0.436	2.7 ± 2.2	0.044, 0.394
Vermicelli Upma	2.1 ± 2.2	–0.101, 0.268	1.6 ± 1.7	–0.287, 0.036	3.0 ± 2.3	0.236, 0.072	2.3 ± 2.0	0.174, 0.141
Fruit Custard	3.2 ± 3.1	–0.195, 0.114	1.9 ± 2.5	0.004, 0.489	2.7 ± 2.6	0.206, 0.101	2.2 ± 2.4	0.125, 0.221

[1]Mean ± SD, [2]r value, [3]p value

(ii) At 120 minutes "*How much would you like to eat now*?". Subjects' ratings varied from 2.9 to 4.9, the lowest rating being given to the reference food – bread. In general, ratings tended to be lower for most of the high-protein variations, whereas the mean ratings for the high-fat variations were higher for almost all the recipes. A significant negative correlation was observed for 83% of the test foods, with the correlations not being statistically significant for only 5 test foods.

(iii) "*Do you feel like eating something else (Nothing at all to A whole meal)*?" For most of the high-protein test recipes, the desire to eat something else was lower. In contrast, the scores for high-fat and high CHO variations were higher (Table 6). For most of the test foods, significant negative correlations were observed.

Table 6: Subjects' Mean Ratings in response to the question 'Do you feel like eating something else'

Test Food	Standard		High Protein		High Fat		High CHO	
Bread (Reference)	2.6 ± 2.3[1]	0.331[2], 0.000[3]						
Sago Kheer	2.1 ± 2.0	–0.103, 0.250	2.5 ± 2.3	–0.429, 0.001	2.7 ± 2.5	–0.408, 0.003	2.6 ± 2.2	–0.471, 0.001
Vegetable Cutlet	2.4 ± 2.4	–0.477, 0.000	1.9 ± 2.0	–0.429, 0.001	2.5 ± 1.8	–0.172, 0.127	1.7 ± 2.0	–0.252, 0.045
Masala Rice	2.2 ± 2.3	–0.218, 0.082	2.0 ±2.2	–0.213, 0.088	1.9 ± 1.8	–0.243, 0.060	2.3 ± 2.2	–0.301, 0.026
Missi Roti	1.7 ± 1.9	–0.380, 0.010,	1.7 ± 2.0	–0.476. 0.001	2.1 ± 1.8	–0.305, 0.033	2.4 ± 2.4	–0.345 0.018
Sandwich	1.9 ± 2.0	–0.026, 0.438	1.7 ± 2.0	–0.209 0.104	2.0 ± 2.0	–0.371 0.010	2.2 ± 2.4	0.100, 0.273
Poha	1.6 ± 1.8	–0.118, 0.244	1.3 ± 1.9	–0.238, 0.078	1.7 ± 1.9	–0.349, 0.017	2.1 ± 2.2	–0.320, 0.027
Stuffed Baati	2.2 ± 2.3	–0.254, 0.059	2.0 ± 2.2	–0.435, 0.003	2.3 ± 2.2	–0.163, 0.160	2.6 ± 2.3	–0.146, 0.187
Vermicelli Upma	1.8 ± 2.0	–0.350 0.013	1.7 ± 1.9	–0.223 0.084	2.3 ± 2.1	–0.462, 0.001	2.2 ± 2.2	–0.144, 0.188
Fruits with Custard	2.1 ± 2.3	–0.273, 0.044	2.5 ± 2.6	–0.399, 0.005	2.3 ±2.2	–0.253, 0.057	1.9 ± 2.2	–0.127 0.217

[1]Mean ± SD, [2]r value, [3]p value

(iv) "*Do you feel like eating something sweet*?" Among the standard recipes, both sweet recipes received lower ratings than the others. Mean scores for high-protein and high-fat variations did not differ greatly for the standard recipes. The ratings for the high carbohydrate variations were lower for most test foods compared to the other variations. Ratings for the desire to eat something sweet were negatively correlated with SI scores for 7 high-protein and high CHO variations, respectively and for 5 high-fat variations. For 61% of the foods, the correlations were statistically significant.

(v) "Do you feel like eating something savoury?" Mean ratings varied from 1.1 to 3.5 with relatively higher ratings for the desire to eat something savoury after consuming all variations of the two test recipes (Table 7). Among the nine recipes, statistically significant negative correlations were obtained for five standard recipes, six high-protein variations, and four high-fat variations but for only one high CHO recipe. Overall mean SI scores for all savoury preparations considered together tended to be significantly higher (120.5 ± 17.2) than sweet preparations (111.8 ± 13.2) (t = -1.690, p = 0.001).

Table 7: Correlation of Subjects' Ratings in response to the question 'Do you feel like eating something savoury with SI Scores

Test Recipe	Standard (r, p)	High Protein (r, p)	High Fat (r, p)	High CHO (r, p)
Bread	–0.330, 0.009	–	–	–
Sago Kheer	–0.038, 0.403	–0.246, 0.001	–0.375, 0.006	–0.240, 0.056
Vegetable Cutlet	–0.578, 0.000	–0.253, 0.045	–0.260, 0.040	–0.124, 0.206
Masala Rice	–0.095, 0.276	–0.300, 0.027	–0.170, 0.140	–0.148, 0.174
Missi Roti	–0.395, 0.008	–0.386, 0.009	–0.311, 0.031	–0.144, 0.197
Sandwich	–0.142, 0.194	–0.163, 0.164	–0.370, 0.010	–0.107, 0.259
Poha	–0.058, 0.367	–0.134, 0.214	–0.031, 0.428	–0.138, 0.208
Stuffed Baati	–0.280, 0.042	–0.461, 0.002	–0.251, 0.062	–0.386, 0.008
Vermicelli Upma	–0.304, 0.028	–0.253, 0.057	–0.065, 0.345	–0.206, 0.101
Fruit Custard	–0.283, 0.038	–0.355, 0.012	–0.158, 0.165	–0.240, 0.068

DISCUSSION

The results of the present study align with published reports suggesting protein has greater satiating efficiency than high-fat and/or CHO foods. (Poppitt et al., 1998; Sivertsen et al., 2010). However, in studies by Rolls et al., (1998), Poppit et al., (1998) and Stubbs et al., (1999) protein provided 60 – 75% of the energy, whereas, in the present study, protein in the test recipes provided much less energy i.e. 30 % in the high-protein variations and 15% in the standard test recipes. Hill and Blundell (1986) and Vanderwater and Vickers (1996) who used a similar percentage of protein preload (33 %) observed significantly increased satiety and a decreased desire to eat. However, reported that increasing protein content from 10-20% did not significantly influence ratings of hunger, fullness or prospective consumption or the onset of the next eating episode (Blatt et al., 2011).

The effect of protein on satiety has been explained by several mechanisms. Anderson and Moore (2004) stated that plasma and especially brain amino acid concentrations rise relatively late after protein consumption. Therefore, satiety signals arising from protein digestion, begin in the gastrointestinal tract via slower stomach emptying, and stimulation of gut hormone receptors such as glucagon-like-peptide 1 and cholecystokinin (Westerterp-Platenga et al., 2009, Moran-Ramo et al., 2012). Protein leads to greater diet-induced thermogenesis compared to iso-energetic amounts of both carbohydrate and fat (Westerterp-Platenga et al., 2009), possibly because of the energy cost for peptide bond synthesis, urea production and/or gluconeogenesis (Halton and Hu, 2004).

The source of dietary protein may be an important factor. The effect of various sources on satiety is required to obtain conclusive evidence. Lueders et al., (2022) suggested that branched chain amino acids may play a role in regulating food intake. Hall et al., (2003) reported that casein was associated with slower gastric emptying than whey protein. Vedhorst and coworkers (2009) reported a greater reduction of hunger by whey as compared to casein and Pal and Ellis (2010) observed that whey protein was more effective in reducing appetite and food intake compared to similar amounts of protein obtained from tuna, turkey and egg albumin. Eggs have also been reported to enhance satiety and decrease energy intake when it was consumed for breakfast (Wal et al., 2008). There are few studies comparing plant versus animal protein and a combination of both. In the present study, a combination of animal (dairy) protein with plant protein was more satiating than either plant protein or animal protein alone. Comparisons of SI scores of sago *kheer* and fruit custard made with milk as the source of protein i.e. with those in which soy was incorporated (*masala* rice, *missi roti* and sandwich) and preparations (*poha*, stuffed *baati* and vermicelli *upma*) containing soy as well as dairy protein from *paneer* (made by coagulating milk with acid and separating the whey), indicated that SI scores were significantly highest for the three recipes that contained a combination of animal and vegetable protein (142.5±68.3) or plant protein (132.1±67.7). However, SI scores of test foods containing only dairy protein were not different from those containing only plant protein. Abou-Samra et al., (2011) reported that a 20g preload of casein and pea protein gave a higher feeling of satiety than did whey protein or egg albumin or maltodextrin. The effect of various protein sources on satiety needs to be studied to obtain conclusive evidence.

Generally, when the effects of protein and fat have been compared, the latter has been substituted by protein which is comparatively less energy-dense (Blatt et al., 2011). However, when energy density was controlled, the satiating effects of the three macronutrients did not differ much (Poppitt et al., 1998; Rolls et al., 1999; Raben et al., 2003). In the present study, the protein was increased at the expense of CHO for four out of the nine recipes whereas, for five test recipes, the fat content decreased by almost half. In the high-fat variations, the protein content was approximately two-thirds the content of the standard recipes. Among the nine recipes, one recipe in the high protein variation had lower mean SI scores than the standard. For the others, the difference between the respective standards and the high protein variation ranged from 7.9 for stuffed *baati* to 38.8 for sandwich. The mean difference for high-protein recipes where the fat content was lowered from approximately 5.5 gm to ≤ 2 gm/portion was approximately 25, whereas for those in which the fat content was approximately 4.9 gm, the difference in SI between the high-protein and standard test recipes was 16.7.

The high-fat variations were less satiating than the high-protein variations. The high CHO variations gave better satiety than the high-fat variations. These findings are in line with studies reported by several authors (Ma et al., 2005; Merchant et al., 2009). High CHO foods may be more satiating than high-fat foods because many high CHO foods contain dietary fibre which can reduce energy intake. Also, high CHO recipes that are dry, may exert more osmotic load compared to high-fat foods containing a similar amount of moisture. In the present study, the high CHO variations of vegetable cutlet, *poha* and *masala* rice were dry compared to the high-fat variations and did confer more satiety. In sago *kheer* and fruits with custard, the sugar content could have increased the osmotic load and contributed to the higher satiety of the high CHO variations of these two test recipes. Besides the CHO content, the type of CHO may be important. Fructose has been found to elicit lower short-term satiety than equivalent doses of glucose or starches. Tappy and Le (2010) proposed two mechanisms for this effect – the glycemic index of fructose is much lower than an equivalent amount of glucose. A fructose-containing meal may suppress the orexigenic hormone ghrelin less, with a lower increase in the satiety hormone leptin.

Fat may have a weak effect on satiety because the satiety signals may be generated by pre-absorptive physiological responses (Stubbs et al., 2008). High-fat foods are usually energy-dense, are more palatable and are likely to be consumed more (Yao and Roberts, 2001; Newby, 2006). In the present study, the high-protein variations generally had a lower ED than the standard test recipes as well as the high CHO and high-fat variations. High-fat variations also took less time to eat. Higher SI scores were negatively correlated with the desire to eat more, which was less for the high-protein variations.

However, other factors like palatability, cooked weight and volume may have contributed to satiety. Cooked weights of the high protein variations were higher possibly because, in six of the nine test foods, soy granules were used. In contrast, the high-fat variations of all the test recipes had lower cooked weights. Cooked weights tended to be positively correlated with satiety as reported by other researchers (Holt et al., 1995, Rolls et al., 2004 and Pai et al., 2005). Lower cooked weights result in higher energy density. Higher cooked weights of the test recipes generally corresponded with greater volume and larger serving sizes. Higher cooked weight/volume may delay gastric emptying, contribute to a feeling of fullness and reduce hunger (Sturm et al., 2004). Mechanical and nutrient stimulation of gastric and post-gastric compartments can play an important role in regulating food intake (Camilleri, 2015).

Significant correlations were observed between ratings for portion size sufficiency and SI scores for seven of the nine test recipes. These findings align with previous reports in the literature (Holt et al., 1995; Pai et al., 2005). Visual cues may influence the perception of sufficiency of portion size and food consumption (Wadhera & Capaldi-Phillips, 2014). Watts et al., (2022) also reported that portion size is controlled by cognitive and physiological factors that play a part during and towards the end of an eating episode. Earlier, Diliberti et al.,

(2004) observed that intakes increased with increasing portion size, regardless of the form of the food. Also, Brunstrom et al., (2011) proposed that humans may have 'expected satiety' regardless of the energy content of the food and may be an important determinant of selected portion size and energy intake. Brunstorm and Shakeshaft (2009) suggested that when deciding on a particular portion size, the individual's strategy may be guided by a concern to ensure that a portion of food will provide adequate satiety. These authors observed that restrained eaters placed greater weight on expected satiety when making decisions about portion size.

Sensory-specific satiety also needs to be considered, since the mean SI scores for the two sweet test foods were significantly lower than the mean scores for the savoury recipes. A decline in the desire to eat more foods of similar taste was reported by Chaaban & Andersen (2021).

In conclusion, the present study shows that the satiety of foods made with plant protein is higher than with dairy protein and can be enhanced by combining both sources of protein. Douglas et al., (2015) found no difference between beef and soy protein however, in a later study by Kristensen and coworkers (2016) high-protein meals provided through beans and peas resulted in lower appetite, hunger and food consumption and higher fullness and appetite, than did meals containing veal and pork. The potential of adding dairy sources to commonly consumed recipes needs to be tested further. Also, the recipes used in the study are typically those used in the Indian sub-continent and would help in improving satiety by manipulating the macronutrient composition.

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