Single vegetable meal content equivalence and alternative to fat for satiety: a randomised trial in Japanese women

A short running title

Minimum vegetable amount for satiety

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Individual contribution

CA collected, analyzed, and interpreted the data and wrote the manuscript; HY-O interpreted the data and contributed to the entire design of the study and the editing of the manuscript; TK supervised the statistical analysis and provided consultations throughout; and HY-O, YT and ET provided significant advice and contributed to the critical revision of the manuscript.

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Abstract

Background: Although high energy density foods are highly palatable, their overconsumption leads to obesity because of high fat content. Low energy density foods are more effective for preventing individuals from becoming overweight. We investigated how different amounts of a single vegetable affect the sensory properties of meals with different energy densities.

Methods: In a randomized crossover design, 40 young Japanese women consumed control and high-fat (HF) lunches. Control meals contained the same amount of rice and hamburger and 80 g (C80), 120 g (C120), 160 g (C160), 200 g (C200), 240 g (C240), or 280 g (C280) of broccoli. HF meals were control meals to which 38.1 g of oil was added (HF80, HF120, HF160, HF200, HF240, and HF280). Sensory properties before intake and 0.5, 1, 2, 3, 4, and 5 h after meals were assessed using a visual analog scale.

Results: Fullness was significantly lower with C80 than with C200 and C280 at 0.5 h and all time points, respectively, after consumption. In contrast, satisfaction with all HF meals was similar at all time points. Fullness and satisfaction were higher with almost all HF meals than with control meals; however, fullness and satisfaction were similar between HF200 and all control meals 1–4 h after consumption.

Conclusions: Fat increases satiety when a single vegetable is included in the meal; however, at least of 200 g of vegetable in a 500-kcal meal with low fat content provides fullness and satisfaction similar to those provided by an HF meal.

Key Words: energy density, vegetable volume, Visual Analog Scale; satiety; dietary guidelines

Introduction

The prevalence of obesity and overweight has been increasing worldwide.[1] The fundamental cause of overweight and obesity has been established as an energy imbalance between calories consumed and calories expended; therefore, eating less and controlling appetite is the most effective method for controlling weight.[2] Furthermore, a well-balanced and sensory-pleasing diet is important for preventing obesity and overweight. Recently, it was reported that dietary energy density (ED) plays an important role in maintaining energy balance and influences energy intake. The energy density (ED) of food is greatly affected by the amount of water and fat it contains.[3] Low energy density (LED) foods include vegetables, fruits, and soups.[4] The addition of LED foods can decrease ED of meals,[5] elevate satiety levels, and lower energy intake.[2,6] The Japanese government recommends that adults should consume at least 350 g of vegetables per day to maintain good health, and it sets 1950 kcal as the estimated energy requirement for 18–29-year-old women.[7] However, most individuals, especially young adults, do not achieve their daily recommended vegetable intake.[8] A high energy density (HED) diet with few vegetables, which readily raises energy intake, leads to imbalanced eating habits and obesity.

Sensory-specific satiety is associated with increased food intake.[9] A strategy to increase vegetable intake is to increase the variety of vegetables in a meal.[10,11] Previous research has shown that an increased variety of foods leads to excessive consumption[12] and that the presence of a variety of vegetables in a meal leads to greater consumption compared with the presence of a single vegetable.[13] Therefore, we examined how the portion size of a single vegetable with different EDs served at lunch influenced fullness and satisfaction in order to determine the minimum amount of vegetable intake required to achieve satisfaction after consuming a low-energy and low-fat meal.

Methods

Subjects

Forty-two healthy, normal-weight Japanese women aged 21–26 years participated in the study. Individuals were questioned in advance whether they disliked any of the food items to be offered in the experimental meals. Halfway through the study, we excluded individuals who were unable to tolerate the test food items (n = 1) and those who were unexpectedly unavailable on the test dates (n = 1). Eventually, a total of 40 subjects successfully completed the study.

All subjects were provided with detailed written and verbal explanations of the general purpose and procedures of the study before written consent was obtained from them. All aspects of the study were approved by the Ethics Committee of the Tokushima University Hospital.

Study design

A randomized crossover design was used to investigate study in lunch. In this trial, control (C) or high-fat (HF) lunches were served to participants twice a week for 6 weeks. The amount of vegetable and ED varied, whereas the amount of hamburger, soybean, and rice remained the same. Control lunches containing 80 g (C80), 120 g (C120), 160 g (C160), 200 g (C200), 240 g (C240), or 280 g (C280) of vegetable, with EDs of 1.25, 1.14, 1.06, 0.99, 0.93, or 0.89 kcal/g, respectively, were provided. HF lunches containing 38.1 g of oil in addition to the same ingredients as those in control lunches were provided. Therefore, HF lunches contained 80 g (HF80), 120 g (HF120), 160 g (HF160), 200 g (HF200), 240 g (HF240), or 280 g (HF280) of vegetable, with EDs of 2.33, 2.11, 1.93, 1.78, 1.66, or 1.56 kcal/g, respectively. The order of 12 meals was randomized across subjects. Subjects were asked to refrain from skipping meals or drinking excessive alcohol and maintain exercise at a consistent level before each scheduled session.

Test meals

An overview of the nutritional information of the test meals is shown in Table 1. With rice as the staple food, the main course comprised hamburger (Prima Meat Packers, Ltd., Japan) with aurora sauce which mixed mayonnaise (Kewpie Co., Ltd., Japan) and tomato sauce (Hikari Foods Co., Ltd., Japan), boiled soybean (Fujicco Co., Ltd., Japan), and broccoli (Ajinomoto Frozen Foods Co., Ltd., Japan) with soy sauce-based salad dressing (Kewpie Co., Ltd., Japan). The composition of C and HF meals was the same except that ED of HF meals was increased by the addition of oil (38.1 g). Subjects were provided with 1.1 L of chilled water that they could consume *ad libitum* throughout the test. If requested, additional water was supplied, but additional food and other drinks were not allowed. The vegetable was boiled broccoli, which was varied consistently in portion size in control and HF meals. The smallest vegetable portion (80 g) was chosen to provide approximately one-third of 233.2 g, which is the mean amount of vegetable consumed per eating session in this age group in a nationally representative sample.[8] The fixed amounts of rice (150 g), hamburger (60 g) with aurora sauce (51.3 g), and boiled soybeans (6 g) was served with all meals. Only the amount of boiled broccoli with soy sauce-based salad dressing was varied. ED of the foods was calculated using the manufacturers' nutrition labels, except those for fiber, which was determined from a food composition table.

Visual analog scale (VAS) ratings

Subjects were asked to rate their fullness, satisfaction, prospective food consumption, and desires to eat savory, sweet, salty, or fatty foods on VAS questionnaires with 100-mm lines for each question.[14] For example, fullness was rated on a 100-mm line preceded by the question "How full are you right now?" and anchored on the left by "not at all" and on the right by "very much". The ratings were filled before intake and 0.5, 1, 2, 3, 4, and 5 h after consuming the meals.

Data analyses

Ratings of fullness, satisfaction, prospective food consumption, and desire to eat savory, sweet, salty, or fatty foods before and at various time points after consuming the test meals were evaluated for specific groups using repeated measures ANOVA followed by Bonferroni post hoc tests. Ratings for control and HF meals with the same amount of vegetable but different EDs were compared using paired t-tests. All statistical analyses were performed using Statistical Package for Social Science software (version 16.0, 2007, SPSS Inc., Chicago, IL, USA). The results are expressed as mean ± SE. A p value of <0.05 was considered statistically significant.

Results

Subjects

Forty women with as average age of 22.6 ± 0.2 years, average weight of 51.5 ± 1.0 kg, average height of 159.0 ± 1.0 cm, and average body mass index (BMI) of 20.4 ± 0.3 kg/m^2 participated in this study.

VAS ratings after consuming control meals with different amounts of vegetable (Figure 1.)

With regard to fullness ratings, C80 scored significantly lower than C200 (p= 0.007), C240 (p = 0.03), and C280 ($p < 0.05$) at 0.5 h, 1 h, and all time points, respectively, after meal consumption. With regard to satisfaction ratings, C80 scored significantly lower than C200 ($p = 0.037$) and C280 ($p = 0.02$) at 4 h after meal consumption. There were no significant differences in VAS ratings for fullness and satisfaction between C80 and C160 at any time point. With regard to prospective consumption ratings, C80 scored significantly higher than C160 at 0.5 h ($p = 0.005$) and 2 h (p = 0.034) after meal consumption, C200 at 0.5 h ($p = 0.000$) and 4 h ($p = 0.014$) after meal consumption, C240 at 0.5 h ($p = 0.001$), 1 h ($p = 0.002$), 2 h ($p = 0.004$), and 4 h ($p = 0.011$) after meal consumption, and C280 at all time points after meals ($p < 0.05$). With regard to ratings for the desire to eat savory food, C80 scored significantly higher than C160 at 3 h ($p = 0.014$) after meal consumption, C200 at 1 h ($p = 0.008$), 3 h ($p = 0.009$), and 5 h ($p = 0.022$) after meal consumption, C240 at 0.5 h ($p = 0.036$), 3 h ($p = 0.000$), 4 h ($p = 0.003$), and 5 h ($p = 0.029$) after meal consumption, and C280 all time points after meal consumption ($p < 0.05$). With regard to ratings for the desire to eat sweet food, C80 scored significantly higher than C160 at 0.5 h ($p = 0.031$) and 1 h ($p = 0.006$) after meal consumption, C200 at 1 h ($p = 0.033$), 3 h ($p = 0.018$), and 4 h ($p = 0.017$) after meal consumption, C240 at 0.5 h ($p = 0.018$), 1 h ($p = 0.012$), 3 h ($p = 0.003$), and 4 h (p = 0.001) after meal consumption, and C280 from 0.5 h ($p = 0.01$)to 4 h ($p = 0.001$) after meal consumption. With regard to ratings for the desire to eat salty food, C80 scored significantly higher than C280 at 0.5 h ($p = 0.016$) and 3 h ($p = 0.011$) after meal consumption. With regard to ratings for the desire to eat fatty food, there were no significant differences in scores for any of the test meals at any time point. In addition, there was no significant difference in VAS ratings for fullness, satisfaction, desire to eat salty food, or desire to eat fatty food among C200, C240, and C280 at any time point.

VAS ratings after consuming HF meals with different amounts of vegetable (Figure. 2)

VAS scores for fullness were significantly lower for HF80 than for HF240 at 0.5 h ($p = 0.036$) and 1 h ($p = 0.019$) after meal consumption and HF280 at 0.5 h ($p = 0.003$) and 1 h ($p = 0.027$) after meal consumption. VAS scores for prospective consumption were significantly higher for HF80 than for HF240 at 2 h ($p = 0.035$) and HF280 at 0.5 h ($p = 0.004$) and 1 h ($p = 0.042$) after meal consumption. With regard to ratings for the desire to eat sweet food, HF80 scored significantly higher than HF240 at 0.5 h ($p = 0.018$) after meal consumption. With regard to ratings for the desire to eat fatty food, HF80 scored significantly higher than HF280 at 1 h ($p = 0.014$) after meal consumption. There were no significant differences in VAS ratings for satisfaction and the desire to eat savory or salty food among any of HF meals at any time point.

VAS ratings for preprandial and postprandial fullness and satisfaction between control and HF meals with the same amount of vegetable

There were significant differences in VAS ratings for fullness between C80 and HF80 ($p < 0.01$), C160 and HF160 ($p < 0.01$), and C240 and HF240 ($p < 0.05$) at all time points after meal consumption and between C120 and HF120 ($p < 0.05$) at all time points except 0.5 h after meal consumption. From 1 h to 4 h after meal consumption, there was no significant difference in VAS ratings for fullness between C200 and HF200, and at 2 h and 3 h after meal consumption, there was no significant difference between C280 and HF280 **(Figure 3-A.)**.

There were significant differences in VAS ratings for satisfaction between C80 and HF80 ($p < 0.05$), C160 and HF160 ($p < 0.05$), and C240 and HF240 ($p < 0.05$) at all time points from 0.5 h to

5 h after meal consumption and between C120 and HF120 at all time points ($p < 0.05$) except 2 h after meal consumption. At 0.5, 1, 2, 3, and 5 h after meal consumption, there were no significant differences in VAS ratings for satisfaction between C200 and HF200. At 0.5 and 3 h after meal consumption, there were no significant differences in VAS ratings for satisfaction between C280 and HF280 **(Figure 3-B.)**.

Discussion

The addition of fat improves the overall palatability of food[15]; however, dietary fat leads to overeating because of high ED and insensitivity to the satiety value of fat.[16] In the present study, we focused on a single vegetable to identify the minimum amount that could provide a high degree of fullness and satisfaction in an easily prepared lunch with or without fat content.

Provision of a variety of foods has been shown to increase food intake in children[17] as well as adults,[18] whereas foods with similar sensory properties decline in perceived pleasantness during consumption.[19] Among control meals, the diet that was highest in vegetables provided fullness and suppressed the desire for prospective consumption and consumption of savory food at all time points after intake; this was in agreement with the conclusion of a recent review that vegetables can decrease dietary ED by adding water-based weight but not energy to foods.[20] Therefore, the weight and, typically, volume of LED foods are more than those of HED foods. The volume of food consumed affects satiety irrespective of ED.[21, 22] With regard to HF meals with 38.1 g of fat content, there were very few significant differences among the VAS ratings for the seven variables at any time point, and this was irrespective of the amount of vegetable. Therefore, the results of the present study do not support the hypothesis that the volume of vegetables has the maximum effect on satiety. However, they do demonstrate that the effects of fat on food intake are related to enhanced palatability, consistent with previous study findings.[23, 24] Earlier investigations indicated that HED foods tend to be more palatable than LED foods because they often contain fat and/or sugar.[25] However, in comparisons between meals containing the same amount of vegetable but different EDs because of varying oil content, few significant differences in VAS ratings for fullness and satisfaction were observed among meals with 200 g of vegetable, suggesting that meals with high vegetables as 200 g might reach similar fullness and satisfaction regardless of addition fat content.

A recent study has reported that the consumption of 240 g of a variety of vegetables in a 500-kcal lunch could achieve and maintain satiety without the addition of oil in the LED model.[26]

Taken together, the findings of our study and previous studies indicate that a diet based on LED meals with a high vegetable content 200-240 g might achieve sufficient satiety.

Limitations of our study include the subject demographics and the use of a single vegetable. Individuals tire easily of a single vegetable. Results could be different in a situation of various vegetables. Marked gender and age differences have been reported with regard to food choice and eating habits.[27] In particular, women are more sensitive to taste than men,[28] and younger subjects are more sensitive to appetite sensations than older subjects.[29,30] Of late in Japan, young adults have not been eating sufficient vegetables, resulting in a habit of HED food consumption. HED foods, which contain fat instead of water or dietary fiber, encourage overconsumption because they are readily available, highly palatable, and inexpensive.[31,32] Furthermore, it can be difficult for some individuals to consume the daily recommended intake of vegetables, which comprises approximately one-third of every meal, because the time spent on cooking and eating varies with mealtime. Further studies are hence required to investigate the effects of a variety of vegetables in conjunction with the effects of gender, age, BMI, and eating habits in order to determine the effects of vegetable portion size on intake over longer periods of time.

In conclusion, a 500-kcal meal containing at least of 200 g of single vegetable provides sufficient fullness and satisfaction without additional fat content in a Japanese lunch. The consumption of even one meal that is high in vegetable content every day may be effective in preventing individuals from becoming overweight. We suggest that specific identification of the amount of vegetable intake capable of providing satisfaction after a meal can be a practical dietary guideline for weight management.

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Conflict of Interest and Funding Disclosure

The authors declare that there are no conflicts of interest.

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Figure Legends

Figure 1. Levels of fullness, satisfaction, prospective food consumption, and desire to eat savory, sweet, salty, or fatty foods on a 100-mm visual analog scale before intake (0 h) and at the indicated time points (0.5, 1, 2, 3, 4, and 5 h) after intake of control meals with different amounts of vegetable. Meals contained 80 g (C80; open circles), 120 g (C120; crosses), 160 g (C160; open triangles), 200 g (C200; closed rhombi), 240 g (C240; closed squares), or 280 g of vegetable (C280, closed circles). Significant differences ($p < 0.05$) at each time point were determined using repeated measures ANOVA followed by Bonferroni post hoc tests and are indicated as follows: a, C80 vs. C160; b, C80 vs. C200; c, C80 vs. C240; d, C80 vs. C280; e, C120 vs. C200; f, C120 vs. C240; g, C120 vs. C280; i, C160 vs. C280; k, C200 vs. C280.

Figure 2. Levels of fullness, satisfaction, prospective food consumption, and desire to eat savory, sweet, salty or fatty foods on a 100-mm visual analog scale before intake (0 h) and at the indicated time points (0.5, 1, 2, 3, 4, and 5 h) after intake of high-fat (HF) meals with different amounts of vegetable. Meals contained 80 g (HF80; open circles), 120 g (HF120; crosses), 160 g (HF160; open triangles), 200 g (HF200; closed rhombi), 240 g (HF240; closed squares), or 280 g of vegetable (HF280; closed circles). Significant differences ($p < 0.05$) at each time point were determined using repeated measures ANOVA followed by Bonferroni post hoc tests and are indicated as follows: c, HF80 vs. HF240; d, HF80 vs. HF280; f, HF120 vs. HF240; g, HF120 vs. HF280; h, HF160 vs. HF240; j, HF200 vs. HF240; k, HF200 vs. HF280.

Figure 3. (A) Preprandial and postprandial fullness on a 100-mm visual analog scale before intake and at various times after control (solid lines) and high-fat (HF; added oil) meal (dotted

lines) consumption. Differences between control and HF meals with the same amount of vegetable but different energy densities were assessed by paired t-tests: *$p < 0.05$ for control vs. HF.

(B) Preprandial and postprandial satisfaction for control and HF meals compared as in A.

Table 1.

Energy and macronutrient composition of the test meals

Item	C80	C120	C160	C200	C240	C280	HF80	HF120	HF160	HF200	HF240	HF280
Broccoli (g)	80	120	160	200	240	280	80	120	160	200	240	280
Soy sauce-based salad dressing (g)	9.3	14.0	18.7	23.3	28.0	32.7	9.3	14.0	18.7	23.3	28.0	32.7
Rice (g)	150	150	150	150	150	150	150	150	150	150	150	150
Adding oil (g)	0	0	0	0	0	0	6	6	6	6	6	6
Chicken hamburger (g)	60	60	60	60	60	60	60	60	60	60	60	60
Aurora sauce (g)	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
Adding water (g)	32.1	32.1	32.1	32.1	32.1	32.1	0	0	0	0	0	0
Adding oil (g)	0	0	0	0	0	0	32.1	32.1	32.1	32.1	32.1	32.1
Boiled soybean (g)	6	6	6	6	6	6	6	6	6	6	6	6
Total												
Weight (g)	357	401	446	491	535	580	363	407	452	497	541	586
Adding oil (g)	0	0	0	0	0	0	38.1	38.1	38.1	38.1	38.1	38.1
Energy (kcal)	445	459	473	486	500	514	845	859	873	886	900	914
Energy Density (kcal/g)	1.25	1.14	1.06	0.99	0.93	0.89	2.33	2.11	1.93	1.78	1.66	1.56
Protein (g)	15.9	17.2	18.6	19.9	21.2	22.6	16.0	17.3	18.6	20.0	21.3	22.6
Fat (g)	11.2	11.4	11.6	11.7	11.9	12.0	56.2	56.3	56.5	56.7	56.8	57.0
Carbohydrate (g)	67.9	69.7	71.4	73.1	74.9	76.6	67.3	69.1	70.8	72.5	74.3	76.0

All values were calculated on the basis of manufacturers' information.

Control (C) and high-fat (HF) lunches contained 80 g (C80, HF80), 120 g (C120, HF120), 160 g (C160, HF160), 200 g (C200, HF200), 240 g (C240, HF240), or 280 g (C280, HF280) of vegetable. HF lunches also contained 38.1 g oil.

Figure 1.

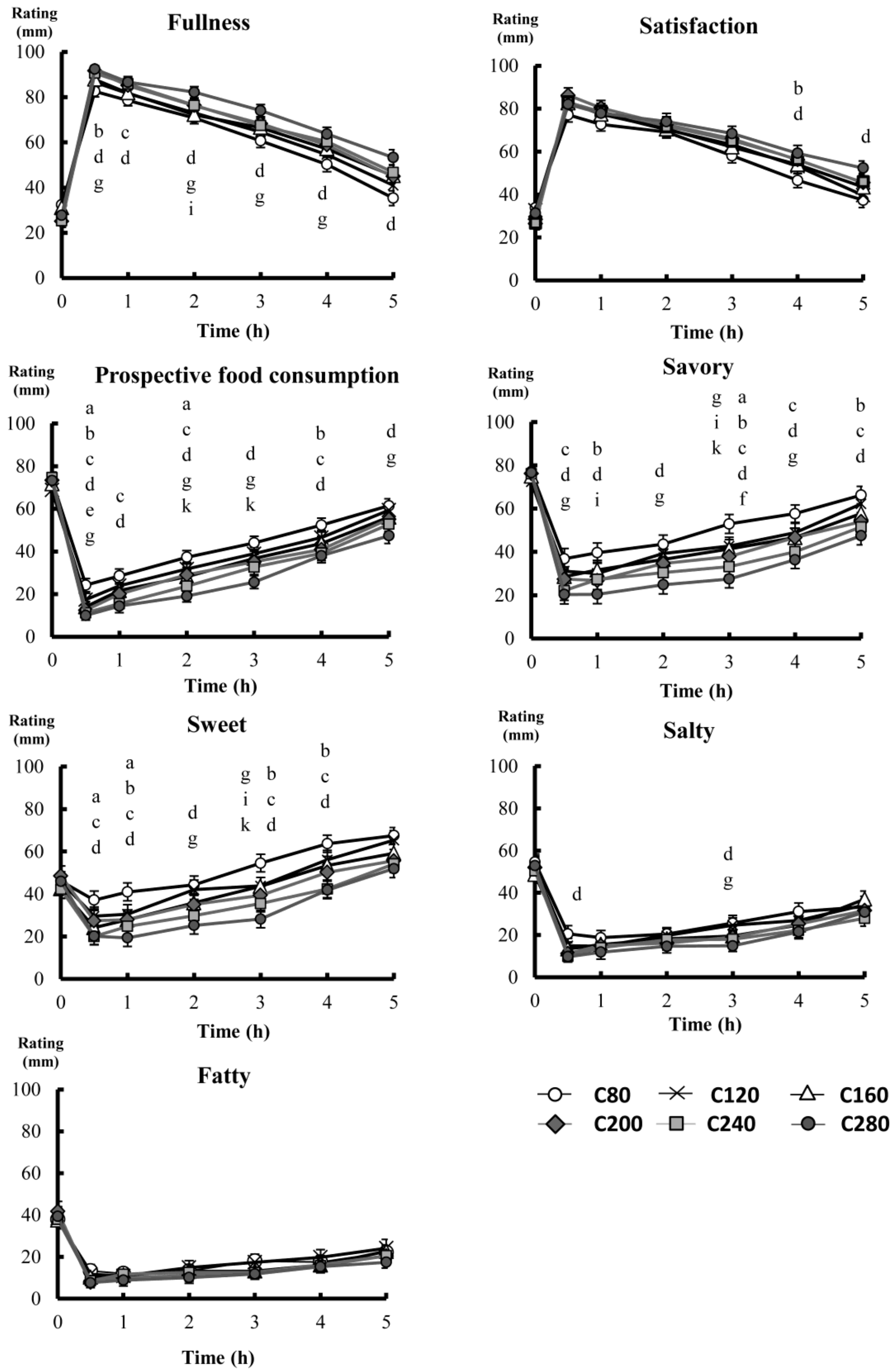
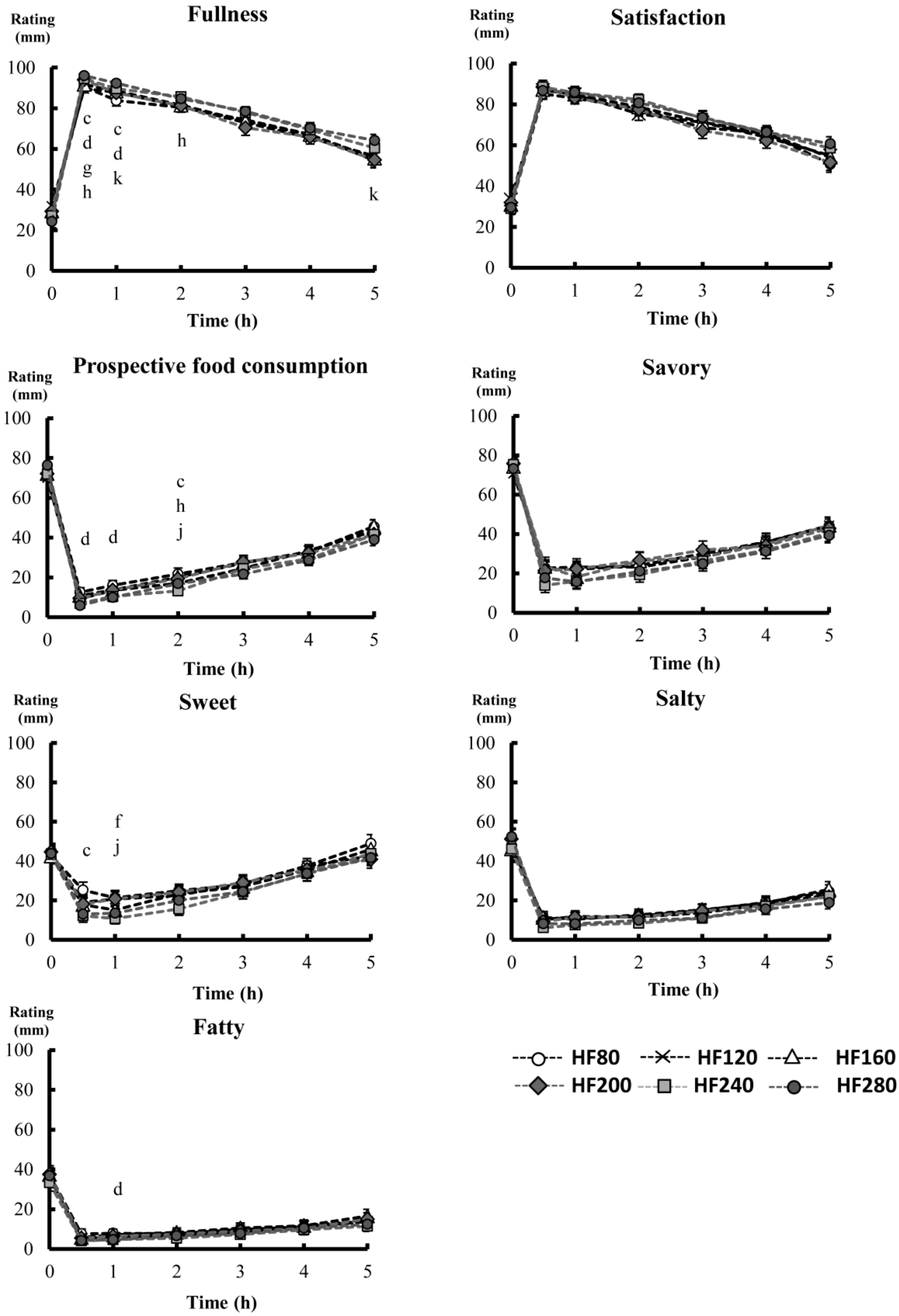

Fullness
Satisfaction
Prospective food consumption
Savory
Sweet
Salty
Fatty
Rating (mm)
Time (h)
C80
C120
C160
C200
C240
C280

Figure 2.


Fullness
Rating (mm)
Time (h)
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Satisfaction
Rating (mm)
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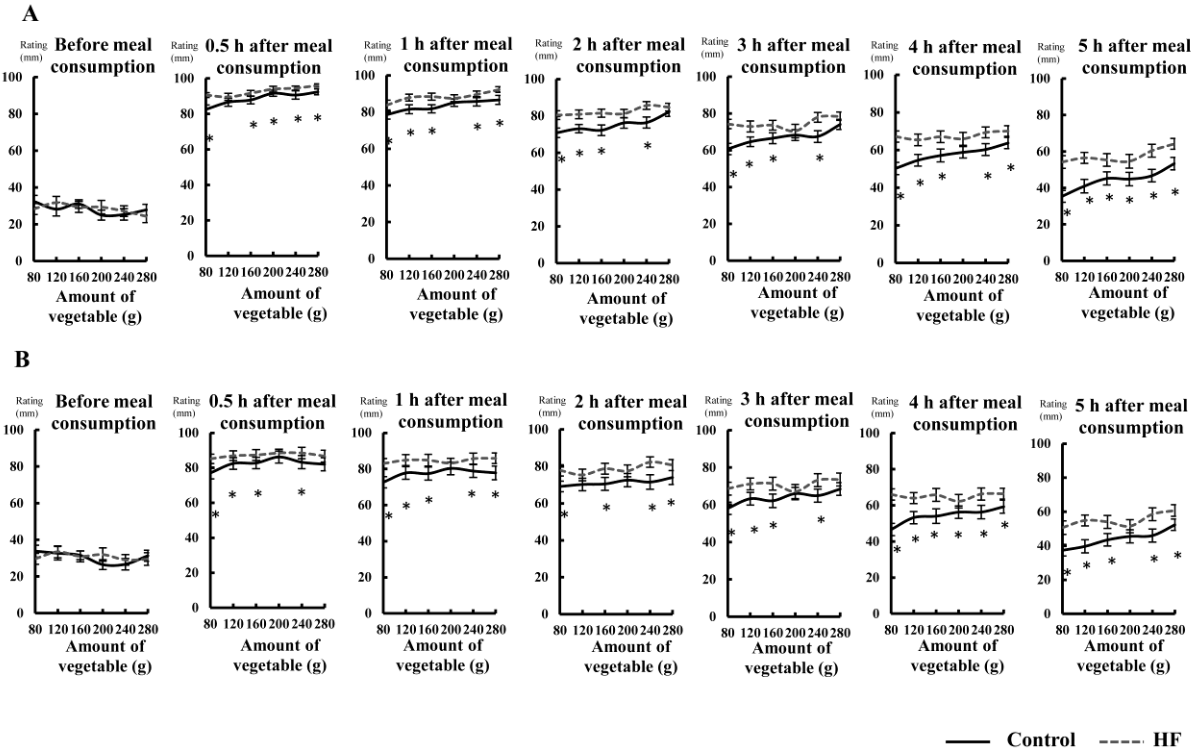
HF120
HF160
HF200
HF240
HF280

Figure 3.


A
B
Rating (mm)
Before meal consumption
0.5 h after meal consumption
1 h after meal consumption
2 h after meal consumption
3 h after meal consumption
4 h after meal consumption
5 h after meal consumption
Amount of vegetable (g)
80 120 160 200 240 280
0 20 40 60 80 100
Control
HF