Short Communication

Food acceptance and anthropometry in relation to 6-n-propylthiouracil sensitivity in Japanese college women

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Background and Objectives: Differences in anthropometry and food acceptance among tasters and non-tasters of 6-n-propylthiouracil has been well studied in Western countries. However, reports on this issue from Asian countries are still limited. **Methods and Study Design:** Healthy Japanese students attending Nara Women's University (n=153) were recruited and classified into 3 groups based on taste sensitivity to a 0.32 mM 6-n-propylthiouracil solution as scored on a labeled magnitude scale. Accordingly, the study population consisted of 34 non-tasters, 78 medium-tasters, and 41 super-tasters. Self-reported food intake was assessed using a food frequency questionnaire. Self-reported food preferences were established using a food checklist listing 63 food items. **Results:** Although subjects in the 6-n-propylthiouracil non-taster group showed a significantly higher body height and weight than subjects in the taster groups, body mass index was comparable among three groups. Intakes of calories, 3 macronutrients, β-carotene and vitamin C did not differ significantly between groups, but the intake of green and yellow vegetables was significantly lower in the taster groups. Among the 5 factors defined by a factor analysis performed with 277 age- and BMI-matched Japanese female students, the taster groups showed a significantly reduced preference for green and cruciferous vegetables alone. **Conclusions**: To the best of our knowledge, this is the first comprehensive report investigating associations between anthropometry, food intake, and food preference in relation to 6-n-propylthiouracil sensitivity in Asian countries. The effect of this tendency towards an aversion to vegetables including cruciferous ones among females on living a healthy life remains to be investigated.

Key Words: 6-n-propylthiouracil, taste acuity, anthropometry, food intake, food preference

INTRODUCTION

Taste perception plays a pivotal role in an individual's dietary life. Among the 5 basic taste perceptions (i.e., sweet, salty, sour, bitter, and umami), the perception of bitter is quite unique in that it has the dual effects of working as an attractant in food and warning of toxic substances.[1] The synthetic compound phenylthiocarbamide (PTC) and the chemically related compound 6-n-propylthiouracil (PROP) were discovered as substances that induce a strong bitter taste in humans.[1,2] The entire human population can be classified as PTC/PROP tasters or non-tasters based on individual sensitivity to PTC/PROP when administered using specific test solutions.[3] As a test solution, PROP use has recently superseded PTC, which was mainly used in earlier studies and has been phased out due to itstoxicity.[4] Phenotypically, it is estimated that approximately 30% of Caucasians and 10~20% Chinese and Japanese are PROP non-tasters.[1] Kim et al[5] identified *TAS2R38,* the specific bitter-taste receptor gene that is responsible for the PTC or PROP bitter taste phenotype. This discovery has made it possible to classify the entire human population into PTC/PROP tasters and non-taster phenotypes based on each individual's genotype.

Building upon the good association between PROP sensitivity phenotype and *TAS2R38* genotype,[6] studies have reported investigations into the characteristics and differences among PTC/PROP tasters and non-tasters based on phenotype and/or genotype classification.

The relationship between PROP sensitivity and food acceptance, including food intake, food preference, and food neophobia, has been one of the central issues investigated in PROP studies.[1,7,8] The basic idea is that PROP tasters, especially super-tasters, may dislike bitter foodstuffs in general and display an aversion to cruciferous

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vegetables, soy products, or tart citrus fruits.[1,7] Several reports also have indicated a negative correlation between PROP sensitivity and body mass index (BMI).[9,10] However, as discussed in several reviews, these hypotheses remain controversial.[1,8,9] Various factors, including ethnicity, age, gender, socio-economic status, and method used to estimate food intake or preference, may explain the heterogeneity among previous reports on this issue. Notably, most studies on this potential outcome of PROP sensitivity have been conducted in Western countries such as the United States[10-15] and European countries.[16,17] To our knowledge, there are only limited reports of investigations of this topic that were conducted in Asian countries.[18-21] Therefore, the aim of the present study was to provide comprehensive information on PROP sensitivity among Japanese college female students and specific anthropometric measures, nutritional/food intakes, and food preferences.

MATERIALS AND METHODS

Study subjects

This study was conducted between April and September 2014 on female Japanese students enrolled at Nara Women's University (Nara city, Japan.). Initially, more than 200 volunteers were recruited to undergo the PROP (Wako Pure Chemical Industry, Ltd., Osaka, Japan) solution test described below. After the test was completed, the purpose and methods of further examination were explained to all applicants and they were invited to participate. Ultimately, 153 subjects agreed to participate. Among them were 119 (77.8%) and 34 (22.2%), PROP tasters (super- and medium-tasters) and PROP non-tasters, respectively. The percentage of non-tasters was almost identical to that identified in our previous study,[22] but was slightly lower than the percentage reported from a previous Japanese study conducted by Inoue et al.[20] All subjects were free from any medication and infection at the time of the examination and did not suffer from a chronic disorder that impacted taste acuity. This project was approved by the ethical and epidemiological committee at Nara Women's University.

PROP sensitivity test

The single solution method originally developed by Lawless[23] was used in combination with a labeled magnitude scale (LMS) for estimating PROP sensitivity.[3,24] In brief, each subject rinsed their mouth with distilled water before the test. After tasting 10 mL of a 0.32 mM solution of PROP dissolved in distilled water, subjects were asked to point out the magnitude of their perception on the LMS. The LMS was 100 mm in length and anchored at the lower end as "barely detectable" and at the upper end as "strongest imaginable". In the current study, we set up the cut-off values for establishing non-tasters (NT) as indicating an LMS ≤15.5 mm, medium-tasters (MT) as between 15.5 and 51 mm, and super-tasters (ST) as ≥51 mm.[3] Consequently, the number of subjects categorized as NT, MT, and ST was 34 (22.2%), 78 (51.0%), and 41 (26.8%), respectively. The taste perception of 0.1 M of sodium chloride was also examined as a reference standard since sodium chloride sensitivity does not vary based on PROP taste status.[3]

Food intake

Self-reported food intake was assessed using a food frequency questionnaire (FFQ) and "Excel Eiyoukun Ver. 5.0" (Kenpakusha, Tokyo, Japan). This software was developed based on "Standard Tables of Food Composition in Japan-Fifth Revised and Enlarged Edition" (Ministry of Education, Culture, Sports, Science, and Technology) and "Dietary Reference Intakes for Japanese, 2010" (Health, Labor and Welfare Ministry).[25] The FFQ has been used in similar studies for evaluating food intake in the study population.[10,12,13] We explained the participants how to estimate the portion sizes by showing the actual pictures of samples beforehand.

Food preferences

The food preference checklist reported by Ullrich et al was used to assess food preferences following some minor modifications.[26] Among the 70 items, we removed seven alcohol-containing beverages listed since individuals less than 20 years old are prohibited from alcohol intake in Japan. The subjects self-described the appeal of each food item presented based on a stepwise 9-point scale; i.e. point-1: most disliked food and point-9: most liked food, based on individual food preference.

Factor analysis of food preferences

To perform a factor analysis, all the checklist samples from 277 Japanese female age- and BMI-matched healthy subjects were collected independently. Then, we performed the factor analysis using the Promax rotation after calculating Pearson correlations between 63 selected foods.[27] Five factors with eigenvalues ≥1.65 and loading co-efficiencies ≥0.4 were extracted and these factors were labeled "fruits", "sweet snacks", "green and cruciferous vegetables", "spicy food", and "sour juices/fruits". The detailed results are presented in the "Appendix". Among the study population, we calculated the checklist food scores for each extracted factor and statistically analyzed the results.

Statistical analysis

Differences between the NT, MT, and ST groups were first examined using the Kruskal-Wallis test. If statistical significance was obtained, differences between each group were evaluated using the Steel-Dwass test. All statistical analyses were carried out using Excel Statistics, Version 2007. *P* values less than 0.05 were considered significant.

RESULTS

Comparison of NT, MT, and ST group anthropometric measures

As shown in Table 1, the NT body height and weight were significantly higher than for MT and ST. However, BMI values were statistically similar among groups.

Comparison of the food intakes among NT, MT, and ST groups

NT, MT, and ST groups exhibited comparable self-reported intakes of calories or 3 macronutrients, β-carotene and vitamin C (Table 2). Table 2 also depicts that among various food groups, intake of green and yel-

Table 1. Subject demographic characteristics

	Non-tasters (NT)	Medium-tasters (MT)	Super-tasters (ST)	*p* value[§]
Number	34 (22.2%)	78 (51.0%)	41 (26.8%)	
Age (years)	20.2 [18-23][§‡]	20.1 [18-26]	20.1 [18-23]	0.95
Height (cm)	162 [151-169][*]	157 [148-170]	156 [150-168]	0.007
Weight (kg)	53.4 [44-71][**]	49.4 [38-70]	48.8 [37-68]	0.0018
BMI (kg/m^2)[†]	20.6 [17.1-25.2]	19.8 [16.2-29.9]	19.9 [15.4-24.7]	0.22

[†]BMI: body mass index.
[‡]Data are the median [range].
[§]Analyzed by Kruskal-Wallis test.
[*]Steel-Dwass test for multiple comparisons. NT vs MT: p=0.017; NT vs ST: p=0.007.
[**]Steel-Dwass test for multiple comparisons. NT vs MT: p=0.034; NT vs ST: p=0.0042.

Table 2. Comparison of nutrients or food intake according to PROP sensitivity

	Non-tasters (NT)	Medium-tasters (MT)	Super-tasters (ST)	*p* value[‡]
Energy and nutrients[†]				
Calories (kcal/day)	1620 [1200-2600]	1620 [1050-2890]	1650 [1190-2190]	0.84
Carbohydrates (g/day)	215 [151-350]	213 [86-339]	216 [124-292]	0.93
Proteins (g/day)	54.1 [29-77]	54.9 [25-78]	54.6 [30-82]	0.95
Lipids (g/day)	55.9 [22-95]	56.9 [24-101]	58.6 [27-87]	0.79
β-carotene (μ g/day)	2300 [440-21400]	2230 [360-6360]	2780 [610-7800]	0.43
Vitamin C (mg/day)	70 [10-242]	59 [16-204]	63 [27-159]	0.35
Food groups[†]				
Green and yellow vegetables (g/day)	92.1 [11-164][*]	64.6 [7-160]	62.6 [14-171]	0.025
Beans (g/day)	46.9 [0-150]	43.4 [0-215]	36.3 [0-165]	0.40
Fruits (g/day)	52.2 [0-214]	55.2 [0-321]	53.3 [0-150]	0.97
Sweet snacks (g/day)	61.0 [0-179]	59.1 [0-233]	59.9 [0-155]	0.87
Flavorings and spices (g/day)	19.7 [2-38]	20.4 [2-32]	21.4 [3-49]	0.89

[†]Data are the median [range].
[‡]Analyzed by Kruskal-Wallis test.
[*]Steel-Dwass test for multiple comparisons. NT vs MT: p=0.033; NT vs ST: p=0.045.

low vegetables including carrot, spinach, tomato, green pepper, Chinese cabbage and Japanese mustard spinach were significantly less in MT and ST groups compared with those in NT groups.

Comparison of food preferences among the NT, MT, and ST groups

As summarized in Table 3, the PROP taster groups (MT or ST) self-reported a significantly lower preference for green and cruciferous vegetables than the NT group. However, group preferences were comparable for the 4 other factors evaluated.

DISCUSSION

Based on taste sensitivity to the bitter compound PROP, a human population can be classified into PROP non-tasters and tasters and sometimes further grouped as non-, medium-, and super-tasters. It has been hypothesized that not only food intake and food preference, but also susceptibility to obesity or certain chronic disorders are different between these groups.[1,7,9] However, study results relevant to this hypothesis have been inconsistent, since they may depend upon the ethnicity, age, gender of the study population along with other environmental factors. For example, in a study of African and Asian Americans, significant differences in liking fatty foods, sugar, and black coffee were observed among the sub-racial groups.[28] Also, Navarro-Allende et al[29] reported the importance of age as an influential factor, since the elderly may be more inclined to try and accept novel foods. Therefore, considering the fact that most reports on this issue were conducted in Western countries, the current study focused on Japanese subjects is thought to provide valuable information for interpreting the role of PROP sensitivity.

In the current study, we have focused on three issues, i.e. anthropometry, food intake and food preference. First, in spite of higher body height or weight in the NT group, BMI was comparable among three groups. This data is consistent with the reports from Asian[18,20] and Western countries.[10,11,14] Conversely, several studies from Western countries reported that the BMI of non-tasters was significantly higher than that of tasters.[10,16] Possible mechanisms for this association include the tendency of PROP tasters to avoid sweet and fatty food stuffs, a role for the cognitive control of eating behaviors, and the participation of the endocannabinoid system.[9]

With regard to the intakes of calories, 3 macronutrients, β-carotene and vitamin C, the current study did not find any significant differences among tasters and non-tasters, which was in line with several previous reports.[16,21] As one of the possible reason why we have not found any differences in calorie intakes among three groups, we speculate that a specific eating behavior based on a strong desire for thinness in female Japanese university students may play a role.[30] However, opposing results showing that non-tasters tended to take more calories than tasters have also been reported.[10,12,20] Related to this difference, researchers have speculated that PROP non-tasters prefer sweeter[31] or higher-fat[32] foods than PROP tasters. In a Tunisian study on the potential relationship between

Table 3. Food preferences according to 6-n-propylthiouracil sensitivity

Factors[†]	Non-tasters (NT)	Medium-tasters (MT)	Super-tasters (ST)	*p* value[‡]
Fruits	6.9 [5-9]	6.5 [3-9]	6.4 [4-9]	0.17
Sweet snacks	5.7 [3-8]	5.6 [2-8]	5.7 [3-8]	0.81
Green and cruciferous vegetables	4.3 [3-6][*]	3.9 [2-5]	3.7 [2-6]	0.012
Spicy foods	4.3 [2-6]	4.5 [2-7]	4.1 [2-7]	0.29
Sour juices/fruits	6.0 [3-9]	5.9 [2-9]	5.4 [1-9]	0.25

[†]Data are the median [range].
[‡]Analyzed by Kruskal-Wallis test.
[*]Steel-Dwass test for multiple comparisons. NT vs MT: p=0.0097; NT vs ST: p=0.012.

PROP sensitivity and taste thresholds for the 4 basic tastes, especially the sweet taste, PROP super-tasters exhibited significantly lower thresholds for sucrose and fructose than PROP medium- and non-tasters.[33] Furthermore, Chang et al[34] performed a whole mouth gustatory test and reported that the thresholds for sweet and bitter tastes decreased sequentially in the order of PROP non-tasters, medium-tasters, and super-tasters. In contrast, our previous study failed to detect any differences among PROP tasters and non-tasters in the thresholds for basic tastes except umami.[22] Thus, whether PROP sensitivity is associated with changes in basic taste acuity, and especially sweetness, remains a topic for further investigation.

PROP contains a thiocyanate moiety that is responsible for its racy bitter taste. Isothiocyanate, a degradation product of glucosinolates, is found abundantly in many vegetables and fruits.[1,14] Green or cruciferous vegetables (e.g., spinach, Brussels sprouts, and asparagus), fruits (grapes, blueberries, and grapefruit), and certain beverages, such as coffee or green tea, are examples of these foods. Therefore, it is speculated that PROP tasters may have a lower intake and less preference for these foods than PROP non-tasters. We have demonstrated that both ST and MT had a significantly lower intake of green and yellow vegetables and lower preference for green and cruciferous vegetables than non-tasters. However, there were no differences between ST and MT groups, indicating that any information gleaned from the further classification of tasters into ST and MT groups may be marginal. Furthermore, the intake or preference for other foods, including beans, spicy foods, and sour juices/fruits did not show any significant differences. Kaminski et al[11] reported that among young women there was a good correlation between the sensation of bitterness between PROP and green vegetables (Brussels sprouts, broccoli, and spinach). Among college-aged adults, the consumption of all vegetables (not restricted to bitter vegetables) was greater among PROP non-tasters.[13] The density of Fungiform papilla on the tongue may also have a role in vegetable preferences. In addition, among tasters, the tendency to avoid the intake of bitter vegetable or greens is more prominent in children than in adults.[17] On the other hand, there are several reports describing no significant differences in cruciferous or green vegetable intake between tasters and non-tasters.[12,19,20]

The current study has several limitations. First, the number of subjects (n=153) was relatively small. In addition, we cannot rule out the possibility of selection bias, since all subjects were recruited as volunteers and only female adolescents were asked to participate. Generalization of the current data requires an additional study involving male and different aged female subjects. Finally, we estimated the food intake of each subject using the FFQ. However, use of an additional method such as a 3-day food intake record would likely make the estimation of food intake more accurate. Despite these limitations, this study provides the first overarching information on differences in anthropometry, food intake, and food preferences among Japanese female PROP tasters and non-tasters. Further exploring the characteristics of food acceptance in relation to PROP sensitivity in a wide variety of Japanese subjects may be helpful to develop their healthy diet life.

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AUTHOR DISCLOSURES
The authors declare that they have no conflicts of interests.

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Appendix. Five factors obtained by factor analysis after Promax rotation in age-matched control subjects

Factor I		Factor II		Factor III		Factor IV		Factor V	
Fruits		Sweet snacks		Green and cruciferous vegetables		Spicy foods		Sour juices/fruits	
Grape	0.81*	Milk chocolate	0.91	Brocolli (cooked)	0.62	Mustard	0.82	Grapefruit juice	0.96
Apple	0.70	Chocolate milk	0.71	Green pepper	0.56	Salsa	0.58	Grapefruit	0.89
Peach	0.59	Ice cream	0.49	Spinach (cooked)	0.50	Tabasco	0.57	Orange juice	0.48
Banana	0.58	Whipped cream	0.41	Radish	0.44	Horseradish	0.54		
Fruits jelly	0.50	Cinnamon buns	0.40	Red cabbage	0.41	Hot pepper	0.48		
Strawberry	0.46			Turnips	0.40				
Eigenvalues	8.24		4.51		3.13		1.94		1.65

*Numbers indicate loading co-efficiencies obtained by Promax rotation