Original Article

Relationship between umami taste acuity with sweet or bitter taste acuity and food selection in Japanese women university students

Masaru Kubota MD, PhD[1,2], Chikako Toda MS[2], Ayako Nagai-Moriyama PhD[3]

[1]Faculty of Agriculture, Department of Food and Nutrition, Ryukoku University, Shiga, Japan
[2]Department of Human Life and Environment, Nara Women's University, Nara, Japan
[3]Faculty of Nutrition, Department of Nutrition, Koshien University, Hyogo, Japan

Background and Objectives: Although there are many studies on the umami receptor and its signaling pathway, literature on the effect of umami taste acuity on dietary choices in healthy subjects is limited. The current study aims to clarify the relationship between umami taste acuity with sweet or bitter taste acuity, food preference and intake. **Methods and Study Design:** Forty-two healthy Japanese female university students were enrolled. The acuity for umami, sweet, and bitter tastes was evaluated using the filter-paper disc method. The study population was divided into 32 umami normal tasters and 10 hypo-tasters based on the taste acuity at the posterior part of the tongue using monosodium glutamate. **Results:** Umami hypo-tasters exhibited a significantly lower sensitivity to sweet tastes than normal tasters. However, the sensitivity to bitter taste was comparable between the two groups. Food preference was examined by the food preference checklist consisted of 81 food items. Among them, umami tasters preferred shellfish, tomato, carrot, milk, low fat milk, cheese, dried shiitake, and kombu significantly more than umami hypo-tasters did. A self-reported food frequency questionnaire revealed no significant differences in the intake of calories and three macronutrients between the two groups; however, umami tasters were found to eat more seaweeds and less sugar than umami hypo-tasters. **Conclusions:** These data together may indicate the possibility that umami taste acuity has an effect on a dietary life. Therefore, training umami taste acuity from early childhood is important for a healthy diet later in life.

Key Words: umami, sweetness, food preference, food intake, filter-paper disc method

INTRODUCTION

Glutamate was identified as the active compound of seaweed "kombu" about 100 years ago.[1] Subsequently, 5'-inosinate from dried bonito "katsuobushi" and 5'-guanylate from dried "shiitake" were also isolated.[2] The taste of these compounds was relatively distinct from the four traditional basic tastes of sweet, salty, sour and bitter, and was termed "umami".[3,4] A synergism between glutamate and other 5'-nucleotides has also been identified.[2,5] Moreover, this synergism has been used in cooking throughout the world.[4]

Two major issues have been primarily studied to achieve a better understanding of the nature of umami taste in human. The first is an elucidation of umami taste acuity in healthy or patient populations. These studies were conducted using monosodium glutamate (MSG)[6] or a mixture of MSG and inosine monophosphate[7] as tastants. Although inconclusive because of a lack of sufficient data, age,[8,9] gender,[10] ethnicity,[11] and obesity[10,12] were proposed as the factors affecting the umami taste acuity in a healthy population. In patients, those with chronic hepatitis C[13] or chronic kidney disease (CKD)[14] were found to suffer from impaired umami taste acuity. The second issue is the analysis of the receptor and subsequent transduction mechanisms responsible for umami taste perception.[3] Recent studies have demonstrated that receptors for umami and sweet tastes belong to taste receptor type1 (T1R) and that bitter taste belongs to taste receptor type2 (T2R).[15] Furthermore, Ozeck et al have shown that these TR family receptors are functionally coupled to inhibitory G protein signaling pathways.[16]

Recently, Sasano et al have proposed an important role for umami taste sensitivity in overall health, especially in the elderly.[17] Despite a large body of evidence on umami taste as described above, the role of umami taste acuity on dietary choices remains to be elucidated. Therefore, the aim of the current study was to clarify: 1) the relationship between umami taste acuity with sweet or bitter taste acuity; and 2) the effect of umami taste acuity on food preference and intake, in Japanese female university students.

Corresponding Author: Dr Masaru Kubota, Faculty of Agriculture, Department of Food and Nutrition, Ryukoku University, Shiga, Japan.
Tel: +81-090-9878-8392; Fax: +81-090-9878-8392
Email: masaru_kubota@chime.ocn.ne.jp
Manuscript received 20 September 2016. Initial review completed and revision accepted 12 October 2016.
doi: 10.6133/apjcn.042017.01

METHODS

Study subjects

This study was conducted in June and July 2014 using Japanese female students attending Nara Women's University. After the initial testing of umami taste acuity by MSG (Ajinomoto Co. Inc., Kawasaki, Japan) in more than 100 volunteers, 42 subjects agreed to participate in further studies. All subjects were free from any medication and infection at the time of the examination and did not suffer from chronic disorders, which are thought to have effect on taste acuity. We took the verbal informed consent from all subjects enrolled in the present study. This project was approved by the ethical and epidemiological committee at Nara Women's University.

Measurement of body height, weight, and oral mucosal moisture

Height was measured to the nearest 0.1 cm, and weight was measured to the nearest 0.1 kg. Body mass index (BMI) was calculated by the formula of weight (kg) divided by the square of height (m). Oral mucosal moisture was determined by the bio impedance value method using an oral moisture checking device with a sensor for capacitance (Life Co., Saitama, Japan). Oral moisture value of over 30% is considered to be normal.[18]

Evaluation of umami, sweet and bitter taste acuity by the filter-paper disc (FPD) method

A single well-trained dietitian (AN) performed the gustatory tests using the FPD method in the morning during a fasting state.[19] Test discs 5 mm in diameter (Taste Disc, Sanwa Chemical Inc., Nagoya, Japan) were placed on either the anterior part of the tongue (AT), which is thought to be innervated by the chorda tympani nerve, or the posterior part of the tongue (PT), which is thought to be innervated by the glossopharyngeal nerve. The substances and concentrations used to test the sweet, bitter, and umami tastes were: sweet (sucrose: 8.8, 74, 292, 584, and 2336 mM), bitter (quinine hydrochloride: 0.025, 0.5, 2.5, 12.5, and 100 mM), and umami (MSG: 1, 5, 10, 50, 100, and 200 mM). The serial dilution of MSG used in the current study was prepared exactly same as that reported by Satoh-Kuriwada et al.[6] The concentrations of each taste were serially scored from disc number 1 (lowest) to number 5 for sweet and bitter tastes, or 6 for umami taste (highest). When the subject could not detect the taste at the highest concentration, a score of 6 for sweet and bitter tastes, or 7 for umami taste was given. The test was initiated with the lowest concentration, which was gradually increased until the taste was recognizable. The subjects' mouth was rinsed with distilled water every time before testing the next concentration. The lowest concentration at which the quality of the taste was correctly identified was defined as the recognition threshold.

Evaluation of food preference

The food preference checklist was designed based on the report from Ullrich et al.[20] Among the initial 70 items, we removed seven alcohol-containing beverages listed, since individuals less than 20 years old are prohibited from alcohol intake in Japan. Instead, we added 18 food items that commonly comprise a typical Japanese diet. The subjects self-described their preference for the resulting 81 food items using a stepwise 9-point scale from 1 (least favorite) to 9 (most favorite). Among the study population, we calculated the checklist food scores for each food and analyzed the results statistically.

Measurement of food intake

A food frequency questionnaire (FFQ) based on "Excel Eiyoukun Ver. 5.0" (Kenpakusha, Tokyo, Japan) was used for assessing the subjects' self-reported food intake. This software was developed based on the "Standard Tables of Food Composition in the Japanese Fifth Revised and Enlarged Edition" (Ministry of Education, Culture, Sports, Science, and Technology) and "Dietary Reference Intakes for Japanese, 2010" (Ministry of Health, Labor and Welfare).[21]

Statistical analysis

Differences in several variables between the umami tasters and hypo-tasters were examined using the Mann-Whitney's U test. All statistical analyses were performed using Excel Statistics, Version 2007. p values less than 0.05 were considered significant.

RESULTS

Comparison of umami tasters and umami hypo-tasters

All subjects were divided into umami tasters and hypo-tasters based on the results of the FPD method at PT using MSG. When the cutoff disc number of four at PT presented by Satoh-Kuriwada et al[6] is used, 32 subjects (76.2%) belonged to the taster group. As shown in Table 1, the anthropometric measures and oral moistures were compared between the two groups. Umami taste acuity evaluated at AT also demonstrated a significantly higher

Table 1. Characteristics in subjects of umami taster and hypo-taster groups

Groups	Umami tasters	Umami hypo-tasters	p values*
Number of subjects	32	10	
Age (yrs)	21 (18-25)†	22 (19-23)	0.16
Height (cm)	159 (144-168)	158 (151-163)	0.80
Weight (kg)	50.3 (38-68.5)	50.5 (43-70)	0.75
BMI (kg/m^2)	20.5 (17.2-24.8)	20.1 (18.4-29.9)	0.71
Oral mucosal moisture (%)	29.5 (23.1-33.1)	30.4 (26.0-32.6)	0.41
Umami taste acuity at AT‡	5 (2-7)	6.3 (5-7)	0.003

†Values indicate the median and range.
‡Umami taste acuity evaluated at the anterior part of the tongue (AT) is shown. The numbers indicate the disc number of the FPD test.
*p values between two groups were determined by Mann-Whitney's U test.

sensitivity in the tasters than in hypo-tasters (Table 1).

Sweet and bitter taste acuity in umami tasters and umami hypo-tasters

Table 2 shows that the sweet taste acuity was significantly impaired in umami hypo-tasters at both AT and PT. By contrast, bitter taste acuity was compared between the two groups.

Food preference in umami tasters and umami hypo-tasters

Among 81 foods commonly used in Japanese diet life, several foods including shellfish, tomato, carrot, milk, low fat milk, cheese, dried shiitake, and kombu were significantly more preferred in umami tasters than umami hypo-tasters. In contrast, fried potato was the only food that was found to be more preferred in umami hypo-tasters (Table 3). There was not any significant difference in other foods not listed in Table 3 among two groups.

Food intake in umami tasters and umami hypo-tasters

As measured by the FFQ, intake of calories and three macronutrients were comparable in both groups (Table 4). Table 4 also shows that umami tasters took significantly higher amounts of seaweeds and less sugar than those in the umami hypo-tasters.

DISCUSSION

It is well known that individual taste perception has an effect on one's food preference and intake.[22] A recent review by Chamoun et al has demonstrated that this phenomenon is closely related to genetic variations of taste receptors.[23] The elderly sometimes consume a greater amount of sweet or salty foods as they experience a decline in taste perception.[24] In clinical settings, for example, patients with CKD ingested higher amounts of sodium in association with an impaired umami and bitter taste acuity.[14] Cancer patients undergoing chemotherapy exhibit lower calorie and nutrient intake associated with impaired sweet and bitter taste acuity.[25] These facts together indicate that the elucidation of gustatory functions in relation to food selection, including food preference, food intake, and hedonic ratings for tasted foods[26] is important for establishing healthy eating habits.

The study population was divided into umami tasters and hypo-tasters based on the sensitivity to MSG by the FPD method at PT. A significant difference in umami taste acuity was also found between the two groups when tested at AT. However, the threshold of each group was much higher at AT compared with that at PT. This fact is consistent with previous reports indicating that there is a significantly greater sensitivity of umami taste perception at PT than at AT.[6,7] Among the five basic tastes, receptors of umami, sweet and bitter tastes comprise one family, since these were found to couple to the G protein, Galpha-gustducin.[15,16] A recent study indicated that calcium homeostasis modulator 1, a voltage-gated ion channel, works as a common channel required for umami, sweet and bitter taste perception.[27] Furthermore, the fact that umami peptides suppress bitter taste via bitter taste receptors demonstrates the interaction between umami and bitter taste at the receptor level.[28] Despite thorough investigation at the molecular level, reports on the comparison of individual umami taste acuity with sweet or bitter taste acuity are limited. In the elderly, a decline in taste perception with age was more prominent in sour and bitter tastes than in salty, sweet, and umami tastes.[24] On the contrary, Sasano et al reported that, among the five basic tastes, only umami taste perception was impaired in some elderly subjects.[17] We were able to compare, for the first time, the sweet or bitter taste acuity in umami tasters and hypo-tasters. Consequently, umami hypo-tasters were found to have a higher threshold for sweet taste acuity. The threshold for the bitter taste did not show a significant difference between the two groups, albeit a marginal increase ($0.05<p<0.1$) was also observed in hypo-tasters. However, the interpretation of these results into a "real world" food perception should be made with caution. Mojet et al presented the possibility that the taste acuity was different when taste substances were dissolved in products other than in water as observed in most studies.[9]

Food selection (i.e., food preference and intake) in relation to the acuity of five basic tastes is one of the major concerns in nutrition. This issue has been extensively studied in a bitter synthetic compound, 6-n-propylthiouracil sensitivity (PROP).[26] The working hypothesis is that PROP-tasters perceive both bitterness and sweetness more strongly and tend to avoid bitter foods (e.g., cruciferous vegetables such as spinach and broccoli) and sweet foods. However, studies on this issue are inconsistent, including our recent report,[29] depending upon the characteristics of the enrolled population (i.e., age, gender, and ethnicity).[26] In the current study, we have demonstrated that umami tasters preferred foods rich in umami (e.g., kombu, dried shiitake, tomato, carrot, milk and cheese), and took more seaweeds in comparison with the hypo-tasters. In addition, although the statistical difference was marginal, umami tasters tended to eat more

Table 2. Comparison of sweet and bitter taste acuity between umami tasters and hypo-tasters

Groups	Umami tasters	Umami hypo-tasters	*p* values*
Sweet taste acuity			
AT†	3 (1-6)	3.5 (3-6)‡	0.048
PT†	2 (1-4)	3 (3-4)	0.009
Bitter taste acuity			
AT	2 (1-4)	2.5 (1-5)	0.091
PT	1 (1-3)	1.5 (1-3)	0.22

†AT indicates the anterior part of the tongue, and PT indicates the posterior part of the tongue.
‡The numbers indicate the disc number of the FPD test. The median number and ranges are shown.
**p* values between two groups were determined by Mann-Whitney's U test.

Table 3. Comparison of food preference between umami tasters and umami hypo-tasters

Foods	Umami tasters		Umami hypo-tasters		*p* values*
	Median (range)	Mean±SD	Median (range)	Mean±SD	
Meat and fishes					
Beef	6 (4-8)	5.7±0.8	6(3-7)	5.5±1.2	0.96
Pork	6 (3-8)	5.9±0.9	5 (3-6)	5.2±0.9	0.089
Chicken	6 (3-9)	6.0±1.2	6 (4-9)	6.2±1.4	0.89
Ham	5 (3-6)	5.0±0.9	5 (2-6)	5.1±1.2	0.47
Sausage	5.5 (2-7)	5.3±1.2	6 (4-8)	5.9±1.1	0.19
White-fleshed fish	6 (3-9)	5.8±1.2	6 (5-7)	5.8±0.6	0.98
Red-fleshed fish	6 (2-7)	5.8±0.9	6 (4-8)	5.7±1.2	0.68
Dorsum blue fish	6 (4-7)	5.8±0.8	5.5 (4-6)	5.4±0.7	0.19
Shrimp	6 (2-7)	5.7±1.2	6 (3-9)	6.0±1.4	0.56
Squid	6 (2-9)	5.4±1.3	5.5 (5-6)	5.5±0.2	0.87
Shellfish	5.5 (1-8)	5.1±1.5	3.5 (1-7)	3.9±1.3	0.048
Vegetables					
Tomato	6 (3-9)	6.4±1.6	5 (3-7)	5.1±1.4	0.033
Onion	6 (3-7)	5.7±0.9	5.5 (5-6)	5.5±0.5	0.34
Pumpkin	6 (4-9)	6.1±0.9	6 (5-9)	6.2±1.5	0.49
Broccoli	5 (2-8)	5.3±1.2	5 (2-6)	4.5±1.2	0.079
Carrot	5 (3-9)	5.2±1.2	4.5 (3-5)	4.3±0.8	0.032
Chinese cabbage	6 (4-7)	5.7±0.9	6 (4-7)	5.7±0.8	0.96
Milk and egg products					
Milk	6 (3-7)	6.2±1.5	5 (2-6)	4.3±1.4	0.003
Low fat milk	4 (3-9)	4.4±1.4	3 (2-5)	3.4±0.8	0.025
Cheese	6 (4-9)	6.3±1.2	5.5 (3-7)	5.1±1.3	0.032
Yoghurt	6 (3-9)	6.3±1.6	6 (3-9)	6.2±1.2	0.98
Egg	6 (4-9)	6.4±1.0	6.5 (5-9)	6.7±1.1	0.57
Mayonnaise	5 (2-6)	4.6±1.1	5 (2-6)	4.7±1.5	0.56
Sweets and snacks					
Ice cream	6 (3-9)	6.1±1.2	6 (4-9)	6.9±1.7	0.20
Chocolate	6 (3-9)	5.9±1.4	6 (4-9)	6.0±1.5	0.39
Cookie	6 (4-8)	5.8±0.9	5.5 (4-8)	5.7±1.2	0.63
Jelly	6 (4-7)	5.5±0.9	5.5 (3-7)	5.3±1.2	0.62
Cake	6 (4-9)	6.2±0.9	6 (4-9)	6.0±1.2	0.35
Fried potato	5 (2-8)	4.8±1.4	6 (5-7)	5.8±0.6	0.026
Nuts	5 (2-8)	4.7±1.2	5 (3-6)	5.0±1.2	0.19
Others					
Butter	5 (3-6)	4.8±0.9	5 (2-7)	4.8±1.3	0.95
Margarine	3.5 (1-6)	3.7±1.5	3.5 (2-5)	3.6±0.9	0.86
Katsuo-bushi (dried bonito)	5 (4-7)	5.2±0.8	4.5 (2-6)	4.5±1.4	0.18
Dried shiitake	5 (2-8)	5.0±1.2	4 (2-6)	3.9±1.5	0.039
Kombu (tangle)	5 (2-8)	4.8±1.4	3.5 (1-5)	3.3±1.5	0.014
Consomme	5 (4-8)	5.3±0.9	5.5 (3-6)	5.4±0.7	0.44
Miso	6 (4-7)	5.5±0.8	5.5 (5-6)	5.5±0.5	0.87

* *p* values between two groups were determined by Mann-Whitney's U test, since they do not mostly show the normal distribution.

Table 4. Comparison of nutrients and food intakes between umami tasters and umami hypo-tasters

Groups	Umami tasters	Umami hypo-tasters	*p* values*
Nutrients†			
Calorie (kcal/day)	1606 (926-2283)	1653 (1241-1898)	0.95
Carbohydrate (g/day)	212 (103-320)	215 (179-235)	0.72
Protein (g/day)	55.2 (32.5-75.4)	54.4 (39.1-67.1)	0.77
Lipid (g/day)	56.2 (26.5-81.5)	58.9 (38.2-76.3)	0.98
Food groups†			
Seaweeds (g/day)	2.9 (0.7-10.7)	1.8 (0-3.6)	0.038
Beans (g/day)	32.5 (5-150)	35 (5-150)	0.71
Green-yellow vegetables (g/day)	69.7 (14.3-182.1)	55.4 (28.6-103.6)	0.073
Milk products (g/day)	139 (0-350)	105 (21-268)	0.064
Snacks (g/day)	54.0 (6.4-145.7)	66.1 (36.9-94.2)	0.24
Fish (g/day)	25.7 (2.9-72.9)	23.6 (5.7-74.3)	0.78
Sugar (g/day)	4.2 (0.9-10.5)	8.1 (2.5-17.9)	0.005

† Nutrients and food intakes were calculated by the self-reported FFQ. The data indicate median and ranges
* *p* values between two groups were determined by Mann-Whitney's U test

green-yellow vegetables (i.e., tomato and carrot)[5] and milk products (i.e., milk and cheese)[30,31] that coincided with the food preference study. By contrast, umami tasters ingested less sugar than hypo-tasters in accordance with the result of sweet taste acuity. The reason why umami hypo-tasters preferred fried potatoes more than umami tasters remains unclear at present. Such food selection tendencies, in general, appear consistent with the results of the taste acuity.

The limitations of the current study are: 1) a relatively small number of enrolled subjects (n=42); 2) the subjects were limited to female adolescents. Given the fact that young Japanese females prefer dieting to become slim,[32] an additional study targeting males and different aged female subjects is necessary; and 3) the food items listed in the food preference checklist did not accord with those in the FFQ. Therefore, a complete comparison between these two studies was rather difficult. Despite these limitations, this study is, to the best of our knowledge, the first report of the relationship between umami taste acuity and (i) sweet or bitter taste acuity, and (ii) food selection, including food preference and intake. The current study may support the previous proposal of an important role for umami taste sensitivity in overall health.[17] Since early food experiences may function as an important factor for establishing food preferences across the lifespan,[33] an introduction of strategies for promoting umami taste acuity from early childhood should be considered.

ACKNOWLEDGEMENTS
The authors would like to thank Enago (www.enago.jp) for their pertinent advice on the present review. The authors are also grateful to Institute for Innovation, Ajinomoto Company Inc.(Kawasaki, Japan) for their supply of monosodium glutamate.

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

REFERENCES
1. Ikeda K. On a new seasoning. J Tokyo Chem Soc. 1908;30: 820-36.
2. Kuninaka A. Research on taste function of nucleotides. J Agr Chem Soc Japan. 1960;34:489-92.
3. Beauchamp GK. Sensory and receptor responses to umami: an overview of pioneering work. Am J Clin Nutr. 2009;90: 723S-7S. doi: 10.3945/ajcn.2009.27462E.
4. Kurihara K. Umami the fifth basic taste: History of studies on receptor mechanisms and role as a food flavor. Biomed Res Int. 2015;2015:189402. doi: 10.1155/2015/189402.
5. Yamaguchi S, Ninomiya K. Umami and food palatability. J Nutr. 2000;130(Suppl 4):921S-6S.
6. Satoh-Kuriwada S, Kawai M, Iikubo M, Sekine-Hayakawa Y, Shoji N, Uneyama H, Sasano T. Development of an umami taste sensitivity test and its clinical use. PLoS One 2014;9:e95177. doi: 10.1371/journal.pone.0095177.
7. Feeney EL, Hayes JE. Regional differences in suprathreshold intensity for bitter and umami stimuli. Chemosens Percept. 2014;7:147-57.
8. Schiffman SS, Frey AE, Luboski JA, Foster MA, Erickson RP. Taste of glutamate salts in young and elderly subjects: role of inosine 5'-monophosphate and ions. Physiol Behav. 1991;49:843-54.
9. Mojet J, Heidema J, Christ-Hazelhof E. Taste perception with age: generic or specific losses in supra-threshold intensities of five taste qualities? Chem Senses. 2003;28: 397-413.
10. Overberg J, Hummel T, Krude H, Wiegand S. Differences in taste sensitivity between obese and non-obese children and adolescents. Arch Dis Child. 2013;97:1048-52. doi: 10. 1136/archdischild-2011-301189.
11. Singh PB, Schuster B, Seo HS. Variation in umami taste perception in the German and Norwegian population. Eur J Clin Nutr. 2010;64:1248-50. doi: 10.1038/ejcn.2010.133.
12. Pepino MY, Finkbeiner S, Beauchamp GK, Mennella JA. Obese women have lower monosodium glutamate taste sensitivity and prefer higher concentrations than do normal-weight women. Obesity (Silver Spring). 2009;18:959-65. doi: 10.1038/oby.2009.493.
13. Musialik J, Suchecka W, Klimacka-Nawrot E, Petelenz M, Hartman M, Błońska-Fajfrowska B. Taste and appetite disorders of chronic hepatitis C patients. Eur J Gastroenterol Hepatol. 2012;24:1400-5.
doi: 10.1097/ MEG.0b013e3283589f63.
14. McMahon EJ, Campbell KL, Bauer JD. Taste perception in kidney disease and relationship to dietary sodium intake. Appetite. 2014;83:236-41. doi: 10.1016/j.appet.2014.08.036.
15. Bachmanov AA, Bosak NP, Lin C, Matsumoto I, Ohmoto M, Reed DR, Nelson TM. Genetics of taste receptors. Curr Pharm Des. 2014;20:2669-83.
16. Ozeck M, Brust P, Xu H, Servant G. Receptors for bitter, sweet and umami taste couple to inhibitory G protein signaling pathways. Eur J Pharmacol. 2004;489:139-49.
17. Sasano T, Satoh-Kuriwada S, Shoji N, Iikubo M, Kawai M, Uneyama H, Sakamoto M. Important role of umami taste sensitivity in oral and overall health. Curr Pharm Des. 2014; 20:2750-4.
18. Takahashi F, Takahashi M, Toya S, Koji T, Morita M. Clinical usefulness of an oral moisture checking device (Mucus). Prosthodont Res Pract. 2006;5:214-8.
19. Nagai A, Kubota M, Katayama Y, Kojima C. Evaluation of taste acuity by the filter-paper disc in Japanese young women: the relationship with micronutrients status. Asia Pac J Clin Nutr. 2012;21:406-10.
20. Ullrich NV, Touger-Decker R, O'sullivan-Maillet J, Tepper BJ. PROP taster status and self-perceived food adventurousness influence food preferences. J Am Diet Assoc. 2004;104:543-9.
21. Ministry of Health， Labour，and Welfare Japan. Dietary Reference Intakes for Japanese, 2010. [2016/08/31]; Available from: http://www.mhlw.go.jp/bunya/kenkou/pdf/blockbetu-shiryou03.pdf#search='RDA+%E6%A0%84%E9%A4%8A+2010. (In Japanese)
22. Loper HB, La Sala M, Dotson C, Steinle N. Taste perception, associated hormonal modulation, and nutrient intake. Nutr Rev. 2015;73:83-91. doi: 10.1093/nutrit/nuu009.
23. Chamoun E, Mutch DM, Allen-Vercoe E, Buchholz AC, Duncan AM, Spriet LL, Haines J, Ma DW; Guelph Family Health Study. A review of the associations between single nucleotide polymorphisms in taste receptors, eating behaviors, and health. Crit Rev Food Sci Nutr. 2016;57:1-14. doi: 10.1080/10408398, 1152229.
24. Sergi G, Bano G, Pizzato S, Veronese N, Manzato E. Taste loss in the eldery: Possible omplications for dietary habits. Crit Rev Food Sci Nutr. 2016;57:3684-9. doi: 10.1080/ 10408398.1160208.
25. Sánchez-Lara K, Sosa-Sánchez R, Green-Renner D, Rodríguez C, Laviano A, Motola-Kuba D, Arrieta O. Influence of taste disorders on dietary behaviors in cancer patients under chemotherapy. Nutr J. 2010;9:15. doi: 10. 1186/1475-2891-9-15.

26. Tepper BJ. Nutritional implications of genetic taste variation: The role of PROP sensitivity and other taste phenotypes. Annu Rev Nutr. 2008;28:367-88. doi: 10.1146/annurev.nutr.28.061807.155458.
27. Taruno A, Vingtdeux V, Ohmoto M, Ma Z, Dvoryanchikov G, Li A et al. CALHM1 ion channel mediates purinergic neurotransmission of sweet, bitter and umami tastes. Nature. 2013;495:223-6. doi: 10.1038/nature11906.
28. Kim MJ, Son HJ, Kim Y, Misaka T, Rhyu MR. Umami-bitter interactions: the suppression of bitterness by umami peptides via human bitter taste receptor. Biochem Biophys Res Commun. 2015;456:586-90. doi: 10.1016/j.bbrc.2014.11.114.
29. Nagai A, Kubota M, Morinaga M, Higashiyama Y. Anthropometric measures and food acceptance in relation to 6-n-propylthiouracil sensitivity in Japanese college females. Asia Pac J Clin Nutr. 2017;26:856-60. doi: 10.6133/apjcn.092016.03.
30. Löliger J. Function and importance of glutamate for savory foods. J Nutr. 2000;130(Suppl 4):915S-20S.
31. Drake SL, Carunchia Whetstine ME, Drake MA, Courtney P, Fligner K, Jenkins J, Pruitt C. Sources of umami taste in Cheddar and Swiss cheeses. J Food Sci. 2007;72:S360-6.
32. Kiriike N, Nagata T, Sirata K, Yamamoto N. Are young women in Japan at high risk for eating disorders?: Decreased BMI in young females from 1960 to 1995. Psychiatry Clin Neurosci. 1998;52:279-81.
33. Ventura AK, Worobey J. Early influences on the development of food preferences. Curr Biol. 2013;23:R401-8. doi: 10.1016/j.cub.2013.02.037.