A taste interaction study using sensory evaluation and a taste recognition device

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(Accepted Feb. 28, 2019)

要　旨：本研究では、呈味の相互作用、とくに酸味が甘味を添加することによって抑制される効果を、官能評価と機器分析によって検証した。なお、機器は都甲によって開発された、脂質／高分子膜を活用した味覚センサーを用いた。被験者は、短期大学に在籍する年齢18〜20歳の健康な女子学生24-27名である。官能評価は、いちご、うんしゅうみかん、キウイフルーツ、グレープフルーツなどの19種類の果汁を試料として実施された。19種類の甘味無添加および甘味添加試料について、いずれも、甘味添加試料は、甘味無添加試料にくらべて、甘味強度の有意な上昇ならびに酸味・苦味強度の有意な低下を認めた（$p<0.01$）。甘味無添加と甘味添加試料の間には、人が感じる酸味強度においては著しい差がみられた。しかし、甘味無添加試料と甘味添加試料については、酸味成分は同じであり、pH値および味覚センサー値においては有意な差がみられなかった。甘味添加によって、官能評価では苦味低下を認めたが、味覚センサー値では、苦味の顕著な減少を示さなかった。

キーワード：甘味、酸味、官能評価、味認識装置

Summary

In this study, we used both sensory evaluation and equipment analysis to study the suppression of sourness using sweetness. The instrument used as a taste recognition device was developed by Professor Toko and utilizes an artificial lipid membrane. The participants were 24-27 healthy female students aged between 18 and 20 years who attended junior college. Sensory evaluations were performed on 19 fruit juice samples such as strawberries, satsuma mandarins, kiwifruits, and grapefruits. For all 19 samples, the sweetness-added samples showed significant increases in sweet intensity and significant decreases in sour and bitter intensities when compared with the sweetness-free samples ($p<0.01$). The number of participants recognizing a difference in sourness intensity between sweetness-free and sweetness-added samples was significant; however, there was no significant difference in pH value and taste sensor output value between the sweetness-free and sweetness-added samples. Sensory evaluation of the sweetness-added grapefruit juice showed a decrease in bitterness, but the results do not show a marked decrease in the taste analysis values.

Key words：sweetness,　sourness,　sensory evaluation,　taste recognition device

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Introduction

A food or drink taste is often experienced in conjunction with other tastes: it is rare that we experience a single taste on its own. When two or more tastes coexist, they fluctuate in quality and intensity, and influence the other flavors present [1]. In general, if a sweetener is added to raw fruit juice with an acidic or bitter taste, the sourness and bitterness are suppressed. For example, when eating grapefruit, granulated sugar is added to suppress the sourness. Previous studies have investigated relationships between the basic tastes of sourness, bitterness and sweetness using sensory evaluation and survey methods [2-5]. In one study, subjects were asked to rate the overall taste intensity, sweetness, sourness, saltiness and bitterness of approximately equi-intense sucrose, NaCl, citric acid and Quinine sulfate stimuli presented alone and in all possible binary, ternary and quaternary mixtures. The results showed a consistent pattern of mixture suppression in which sucrose sweetness tended to be both the least suppressed quality and the strongest suppressor of other tastes [4]. There have been no reports on sensory evaluation using instrument analysis. In this study, we used both sensory evaluation and equipment analysis to study the suppression of sourness using sweetness. The instrument used as a taste recognition device was developed by Professor Toko and utilizes an artificial lipid membrane [6].

Materials and Methods

1. Samples

Table 1 lists the samples used in the sensory evaluation, and Table 2 lists the samples measured using the taste recognition device. Food item numbers are based on the Standard Tables of Food Composition in Japan (MEXT, Japan 2018)[7]. Raw fruits were cut into 2cm square and raw fruit juice was prepared with a juicer (TJ111: TESCOM, Japan). In this study, granulated sugar was added to raw fruit juice and is subsequently referred to as sweetness-added juice.

2. Instrumental measurements of sample components

The pH (pH meter: KS701 Shin Denko Kogyo) and Brix (Brix (%) meter: Atago handheld refractometer) of 19 samples were measured 3 to 6 times (Table 1). Citrus fruit juices contain many different alkaloid-type bitterness tastes, and it is suggested that the different bitterness tastes vary in the way they are received [8]; therefore, bitterness-before and bitterness-after were measured separately. Table 2 shows four samples for which "taste recognition device output values of sweetness, sourness, bitterness-before and bitterness-after" were measured using a taste recognition device(Intelligent sensor technology, TS-5000Z), and taste estimates were calculated. Hereinafter, these are the taste output values and the taste estimates, respectively.

3. Sensory evaluation

The participants were 24-27 healthy female students (total numbers) aged between 18 and 20 years who attended junior college. The participants underwent a preliminary experiment and a training session before participating in the experiments. The preliminary experiment examined the conditions for carrying out the experiment, and the training session was based on the 7-point scale method (Yamano, 2003) using samples. During the experiment, sensory evaluations were conducted in an air-conditioned, quiet room according to the method described below. The room contained a desk for testing, as well as a water supply and a sink for gargling. Sensory evaluations were conducted around 4 pm when the participants were neither hungry nor full. Samples were presented at room temperature (20 ± 2°C) in white paper cups.

To begin, participants washed their mouths with pure water before 15g (or mL) of sample was given. Participants then tasted 3-5g(or mL)of sweetness-free juice using their whole mouth for 20 seconds. The mouth was then washed again before sweetness-added juice was tasted using the whole mouth for 20 seconds. On the day of the experiment, sensory evaluation was performed using two types of sample. Each participant evaluated 38 samples using the 7-point scale (-3 to +3) [1]. The following five evaluation items were used for taste intensity: sweet, sour, bitter, taste balance and palatability. For example, sweet taste intensity was scored as follows: significantly sweeter +3, fairly sweeter +2, slightly sweeter +1, same 0, slightly less sweet -1, fairly less sweet -2 and significantly less sweet -3. The evaluation scale was set at equal intervals.

This study was approved by the Educational Research Committee of Suzugamine Women's College: approval number 2016-07. Prior to the sensory evaluation, the participants were informed of the purpose of this study, the safety of the fruit samples, and that their participation was voluntary and their personal information would be strictly protected. Written, informed consent was obtained from all participants before commencing this study.

Table 1. Samples for sensory evaluation

	Food for raw fruit juice	Food number [7]	Production areas
Sweetness-free juice	Tomato	06182	Kumamoto
	Strawberry ; Toyonoka	07012	Saga
	Satsuma mandarin ; Ocho	07027	Hiroshima
	Kiwifruit	07054	New Zealand
	Grapefruit ; White	07062	U.S. A
	Watermelon ; Maderball	07077	Kumamoto
	Watermelon ; Yellow pulp species	07077	Tottori
	Japanese pear ; Kosui	07088	Hiroshima
	Natsumikan ; Amanatsu	07093	Hiroshima
	Pineapple	07097	Philippines
	Papaya	07109	U.S. A
	Grape ; Delaware	07116	Fukuoka
	Grape ; Kyoho	07116	Hiroshima
	Blueberry	07124	Hiroshima
	Melon	07134	Kumamoto
	Peach ; Hakuto	07136	Okayama
	Lychee	07144	China
	Apple ; San Fuji	07148	Aomori
	Lemon	07155	Hiroshima
Sweetness-added juice	We added granulated sugar to the raw fruit juice ; 10% Sweetness Concentration (w/v) Granulated sugar ; Mitsui Co., Ltd.		

Table2. Samples of grapefruit juice for taste recognition device measurement

	Food for raw fruit juice	Food number	Production areas
Sweetness-free juice	Grapefruit ; White	07062	U.S. A
Sweetness-added grapefruit juice	We added granulated sugar to the raw grapefruit juice ; 5.0, 10.0, 20.0% Sweetness Concentration (w/v) Granulated sugar ; Mutsui Co., Ltd.		

4. Data Analysis

The evaluation score, Brix, pH and taste sensor output value for each sample was expressed as the mean ± standard deviation. Each variable was tested by the Shapiro-Wilk test for normality. To compare the scores between sweetness-free and sweetness-added samples, a paired sample *t*-test was used [9]. Sensory evaluation data are shown by radar charts, and the taste estimates of bitterness is represented by two dimensional scatter plots. IBM SPSS Statistics 25.0 for Windows (IBM Company, Tokyo, Japan) was used for statistical analysis.

Results

1. Sensory evaluation for sweetness-free and sweetness-added fruit juice

Sensory evaluations were performed on 19 fruit samples. The sensory evaluation charts presenting the sweetness-free and sweetness-added sample results for strawberries, satsuma mandarins, kiwifruits, grapefruits, natsumikans and Delaware grapes are shown in Figs. 1 to 6, respectively. In each chart, the score at the center is -3 and this increases towards the outer edge to +3. After adding sweetness to the strawberry juice, the sweet taste intensity increased from -0.3 to +2.2, the sour taste intensity decreased from 0.7 to 1.8 and bitterness intensity decreased from -0.1 to -2.5. The sweet taste intensity significantly increased and the sour / bitterness taste intensity significantly decreased after adding sweetness to the six samples in Figs. 1 to 6 (p<0.01). The same results were obtained for 13 other samples (data not shown).

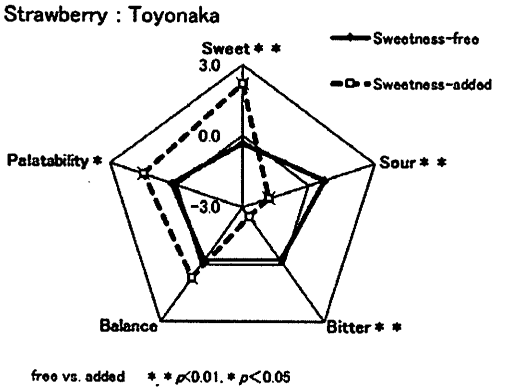

Fig.1. Sensory evaluation chart with the strawberry

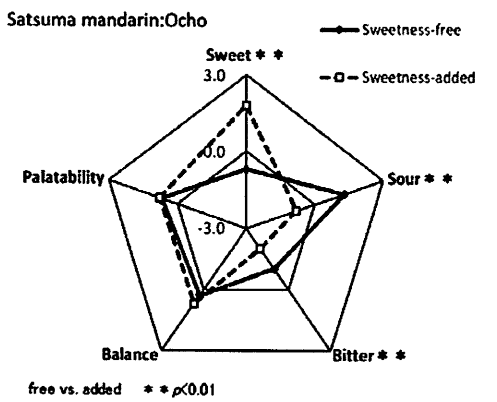

Fig.2. Sensory evaluation chart with the satsuma mandarin

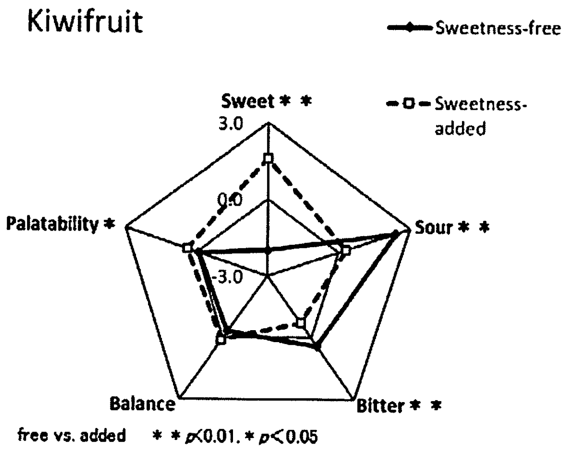

Fig.3. Sensory evaluation chart with the kiwifruit

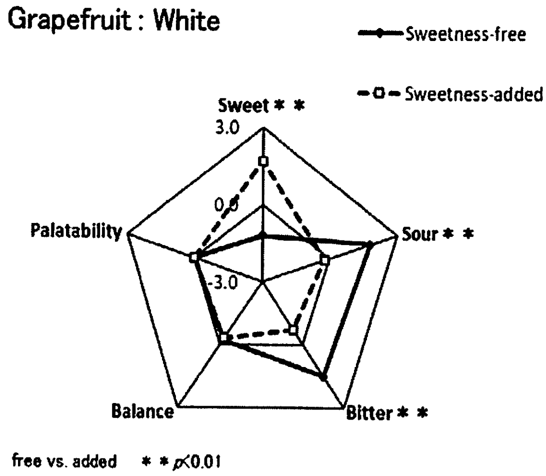

Fig.4. Sensory evaluation chart with the grapefruit

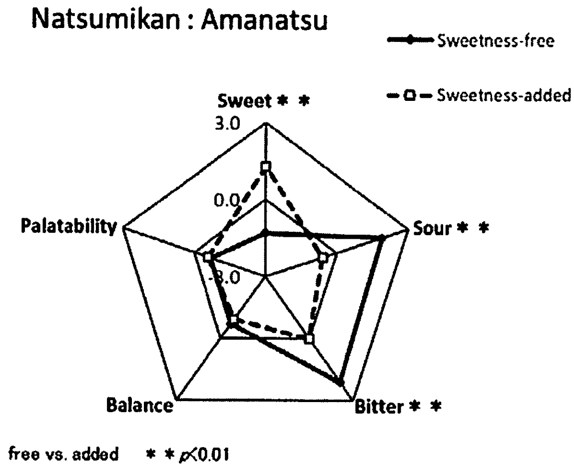

Fig.5. Sensory evaluation chart with the natsumikan

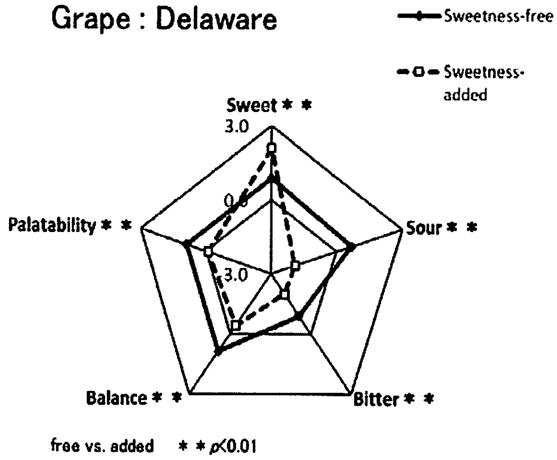

Fig.6. Sensory evaluation chart with the grape

2. Brix and pH in sweetness-free and sweetness-added fruit juice

Table 3 shows the Brix (%) and pH of sweetness-free and sweetness-added samples. The 19 sweetness-free samples had Brix values between 4.0 to 20.0 and pH values between 2.5 to 5.6. The 19 sweetness-added samples had Brix values between 13.3 to 27.0 and pH values between 2.6 to 5.6. There was a significant difference in Brix between sweetness-free and sweetness-added samples ($p<0.01$), but there was no significant difference in pH.

3. Taste output values for grapefruit juice samples

Table 4 shows taste sensor output values for grapefruit samples based on a standard solution; this solution is a zero standard solution in the taste recognition device, which corresponds to human saliva. When a solution has a taste output value of zero or more, it is regarded as having a taste. No significant difference in sour or salt taste was observed in the grapefruit juice samples between the sweetness-free and the sweetness-added samples: even when sweetness was added, the taste values did not change. The sweet output values were significantly increased when sweetness was added (p<0.05) and both the bitter-before and after values were significantly decreased after adding sweetness.

Table 3. Brix and pH of sweetness-free and sweetness-added samples

	Brix (%)			pH		
	Sweetness-free samples	Sweetness-added samples	comparisons	Sweetness-free samples	Sweetness-added samples	comparisons
Tomato	4.0±0.0	13.3±0.2	**	4.6±0.0	4.6±0.1	n. s.
Strawberry; Toyonoka	7.0±0.0	15.3±0.2	**	3.7±0.5	3.7±0.2	n. s.
Satsuma mandarin ; Ocho	10.0±0.0	19.0±0.2	**	3.8±0.0	3.8±0.1	n. s.
Kiwifruit	14.0±0.0	21.0±0.2	**	3.3±0.1	3.3±0.1	n. s.
Grapefruit ; White	9.3±0.3	19.0±0.2	**	3.4±0.1	3.4±0.1	n. s.
Watermelon ; Maderball	8.0±0.2	16.0±0.3	**	5.6±0.1	5.6±0.1	n. s.
Watermelon : Yellow pulp species	9.0±0.0	14.7±0.2	**	5.3±0.2	5.3±0.1	n. s.
Japanese pear ; Kosui	8.0±0.0	16.3±0.2	**	5.2±0.1	5.1±0.1	n. s.
Natsumikan ; Amanatsu	10.0±0.1	18.0±0.6	**	3.1±0.1	3.1±0.1	n. s.
Pineapple	12.0±0.1	19.0±0.3	**	3.9±0.0	3.9±0.0	n. s.
Papaya	9.0±0.2	16.0±0.2	**	5.5±0.1	5.5±0.0	n. s.
Grape ; Delaware	20.0±0.2	27.0±0.3	**	3.5±0.1	3.5±0.0	n. s.
Grape ; Kyoho	15.0±0.1	23.0±0.3	**	3.5±0.1	3.5±0.1	n. s.
Blueberry	12.0±0.2	19.8±0.2	**	2.9±0.1	2.9±0.1	n. s.
Melon	11.0±0.2	19.8±0.5	**	6.3±0.0	6.3±0.1	n. s.
Peach ; Hakuto	10.0±0.2	19.0±0.2	**	4.3±0.1	4.3±0.0	n. s.
Lychee	15.0±0.0	21.0±0.4	**	5.5±0.1	5.5±0.0	n. s.
Apple ; San Fuji	13.0±0.0	21.0±0.3	**	4.2±0.1	4.2±0.1	n. s.
Lemon	10.0±0.1	16.0±0.1	**	2.5±0.0	2.5±0.0	n. s.

The score for each sample was expressed as the mean ± standard deviation (n=3-6). All fruits samples were used as fresh produce. Sweetness-free and sweetness-added samples were compared. A paired sample t-test was performed between sweetness-free and added samples at each score. ** p<0.01, n. s. not significant

4. The taste estimates in bitter-before/after for grapefruit juice samples

Taste estimates were calculated using sweetness-free grapefruit juice as the standard zero solution. A sample concentration difference of 20% is measured as 1.0 using the taste recognition device. The majority of people can detect a concentration difference of 20% as a different taste; however, very few people can identify a difference in taste estimate of 0.5 or below [10-11]. Fig. 7 shows a two-dimensional scatter plot based on the bitter taste estimates for the before and after tastes of grapefruit juice: the difference in taste estimates between the sweetness-free and sweetness-added samples was 0.5 or less, and most participants did not detect a different taste between the samples.

Table 4. Taste sensor output value of grapefruit juice based on standard solution

	Sweetness-free	Sweetness-added		t-value
Sweet	1.84±0.15	Added 5.0%(w/v)	3.24±0.25	-6.09*
		Added 10.0%(w/v)	3.40±0.40	-4.91*
		Added 20.0%(w/v)	4.46±0.46	-7.44*
Sour	15.18±0.02	Added 5.0%(w/v)	15.18±0.18	0.000
		Added 10.0%(w/v)	15.25±0.25	-0.45
		Added 20.0%(w/v)	15.37±0.37	-0.84
Salt	12.67±0.02	Added 5.0%(w/v)	12.66±0.66	0.03
		Added 10.0%(w/v)	12.65±0.35	0.11
		Added 20.0%(w/v)	12.67±0.17	0.000
Bitter first-taste	0.94±0.02	Added 5.0%(w/v)	0.80±0.05	8.08*
		Added 10.0%(w/v)	0.75±0.05	4.70*
		Added 20.0%(w/v)	0.69±0.04	7.22*
Bitter after-taste	0.96±0.02	Added 5.0%(w/v)	0.85±0.05	6.35*
		Added 10.0%(w/v)	0.77±0.02	8.23*
		Added 20.0%(w/v)	0.73±0.07	7.97*

The score for each sample was expressed as the mean ± standard deviation (n=3). This standard solution is a zero standard solution in "the taste sensor", which corresponds to human saliva. When an output value of zero or more is obtained, it is judged that there is any taste. A paired sample t-test was performed between sweetness-free and added samples at each score. * $p<0.05$

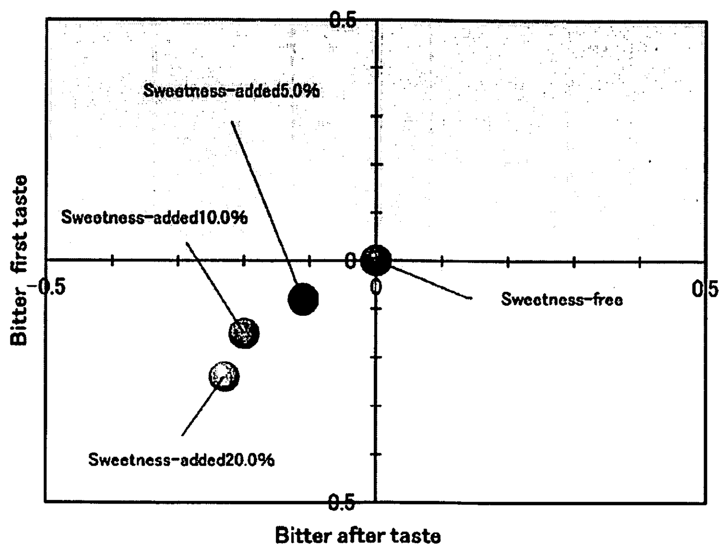

Fig.7. Two-dimensional scatter plot of bitterness of grapefruit juice

In the taste sensor, the difference in the taste estimate value of 1.0 is a concentration difference of 20%, which is the concentration difference that the majority of people feel different tastes.

Discussion

For all 19 samples, the sweetness-added samples showed significant increases in sweet intensity and significant decreases in sour and bitter intensities when compared with the sweetness-free samples($p<0.01$). The number of participants recognizing a difference in sourness intensity between sweetness-free and sweetness-added samples was significant; however, there was no significant difference in pH value and taste output value between the sweetness-free and sweetness-added samples. Possible reasons why the sensory evaluation differed from the values recorded by the equipment include: (i) sour components soak into the taste cells of the taste buds in the human mouth where they bind to the sour taste receptors, excite the taste cells and release neurotransmitters. The neurotransmitters are then converted into a pulsed electrical signal, which sends information to the brain via the taste nerve, and humans receive a sour taste. In the brain sour acceptance process, taste information interaction may occur [12]. (ii) the taste recognition device [6] can quantify 5 basic and astringent tastes by converting the information particular to the taste component into a voltage with the lipid / polymer membrane. This membrane responds to the taste itself and not to individual taste components. The taste sensor can extract a taste substance in the solution using selective electrodes but there is no interaction between the electrodes: in humans, there is an enhancement or suppression of taste information at the brain cell level, but the taste sensor instrument cannot process such interactions. Both the sensory evaluation and taste output values showed a significant decrease in bitterness taste when sugar was added to the grapefruit juice; however, since the difference in taste estimates between the sweetness-free and sweetness-added was 0.5 or less, it is considered that most people cannot differentiate between the small difference in taste[10-11]. Sensory evaluation of the sweetness-added grapefruit juice showed a decrease in bitterness, but the results do not show a marked decrease in the taste analysis values. Further research to clarify the interaction mechanism of taste acceptance in vivo is required to understand how different tastes enhance or suppress each other and how this is received by humans.

Conclusion

There was no significant difference in pH and "taste analysis values" between the sweetness-free fruit juice and the sweetness-added fruit juice, but significant differences were found in the sourness and bitterness intensity experienced by humans during the taste test.

Acknowledgements We received advice from Mr. Takahiro Takahashi in Taste & Aroma Strategic Research Institute Co.,Ltd.. We appreciate him.

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