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Evaluation of bottled nutritive drinks using a taste sensor

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Abstract

The purpose of this study was to evaluate the taste of 20 bottled nutritive drinks, all commercially available on the Japanese market, both in human gustatory sensation tests and using a multi-channel taste sensor. In the gustatory sensation tests, seven trained healthy volunteers were asked to score the drinks in terms of the intensities of four basic tastes (sweetness, saltiness, sourness, and bitterness), for overall palatability (ease of drinking), and for nine components of palatability (astringency, pungency, fruitiness, tasting of a medicinal plant, refreshing, irritating to the throat, seeming beneficial, good aftertaste, and the desire to drink again). The data were analysed to determine the critical factors for overall palatability.

There was a positive linear correlation between overall palatability and 'sourness', 'fruitiness', 'refreshing', and 'good aftertaste' scores ($r = 0.79$, 0.85, 0.74, and 0.70, respectively). There was a negative correlation between overall palatability and 'bitterness intensity', 'tasting of a medicinal plant', 'seeming beneficial', and 'pungency' scores ($r = -0.76$, -0.64, -0.62, and -0.50, respectively).

When evaluated using a multi-channel taste sensor, there was a positive linear correlation between the intensities of sourness and bitterness determined by the human volunteers and those predicted by the taste sensor ($r = 0.85$ and 0.71, respectively). The pungency intensity, as evidenced in gustatory sensation tests, could be also predicted by sensor output ($r = 0.84$). The taste sensor seems therefore to be a potentially useful tool in evaluating the palatability of bottled nutritive drinks.

Keywords: Nutritive drinks; Taste sensor; Sweetness; Sourness; Bitterness; Palatability

1. Introduction

Many bottled nutritive drinks are available on the Japanese market for indications such as chronic fatigue, to aid recovery, to maintain nutrition in patients with a weak constitution or chronic illness, and for supplementation of nutrients. These drinks contain many different combinations of ingredients, including vitamins, minerals, amino acids, and active components of medicinal plants, and consequently differ considerably in taste. Several different approaches have been made to achieve satisfactory flavouring or taste-masking of these drinks, as their palatability has been shown to be directly correlated with marketability. As in the case of physical taste-masking using polymers successful in solid formulations (Yajima et al., 1999; Choi and Kim, 2000), different additives have been used to improve palatability in nutritive drinks. There has been no systematic study in which the tastes of these nutritive drinks have been compared objectively.

We have previously demonstrated the usefulness of the artificial taste sensor to predict tastes such as bitterness (Miyanaga et al., 2002; Uchida et al., 2003). The

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taste sensor was originally developed by Toko (1998), and has been used in various trials to determine the taste characteristics of foods or beverages such as beer, sake, and green tea, etc. (Taniguchi and Ikezaki, 2001). In the present study, we examined the taste of 20 commercially available bottled nutritive drinks, using human gustatory sensation tests and the artificial taste sensor. The nutritive drinks are marketed for fatigue or to aid recovery (16 products), or for patients with tired eyes and stiff shoulders (four products). In the gustatory sensation tests, intensity scores were given for four basic tastes (sweetness, saltiness, sourness, and bitterness), for overall palatability, and for nine components of palatability (astringency, pungency, fruitiness, tasting of a medicinal plant, refreshing, irritating to the throat, seeming beneficial, good aftertaste, and the desire to drink again). The data were analysed to determine the critical factors for overall palatability.

The taste sensor was also used to quantify the relationship between the most critical tastes (bitterness, sourness, and pungency) of the nutritive drinks and their overall palatability. In addition, the relationship between overall palatability and price of product was examined using principal component (PC) analysis.

Table 1
The commercially available bottled nutritive drinks used in the study

Price group	Trade name	Company name
Low	L1	A
	L2	B
	L3	C
	L4	D
	L5	E
	L6	F
	L7	F
Middle	M1	B
	M2	G
	M3[a]	G
Middle/high	MH1	B
	MH2[a]	D
	MH3[a]	G
	MH4[a]	G
	MH5[b]	B
	MH6[b]	H
	MH7[b]	C
	MH8[b]	G
High	H1	F
	H2	C

[a] Products containing medicinal plant ingredients.
[b] Tired eyes and stiff shoulders.

2. Methods

2.1. Materials

The 20 bottled nutritive drinks used in the present study are listed in Table 1, grouped according to price. Seven products belong to the low-price group (about 150 yen), three to the middle-price group (about 300 yen), eight to the medium/high-price group (about 500 yen), and two to the high-price group (about 1000 yen). The products for patients with tired eyes and stiff shoulders all fell into the medium/high-price group. The products are marketed by eight different companies, represented by the letters A–H in the right-hand column.

2.2. Gustatory sensation tests

The gustatory sensation tests were conducted with seven trained healthy human volunteers according to a previously described method (Indow, 1966; Katsuragi et al., 1997). Standard solutions representative of four basic tastes (quinine sulfate for bitterness, sucrose for sweetness, tartaric acid for sourness, and sodium chloride for saltiness) were prepared by dissolving different concentrations of the substances in distilled water (see Table 2). Before testing, the volunteers were asked to keep the standard solutions in their mouths for 10 s, and were told scores (from 1 to 5). After tasting a 2 mL sample of an unknown bottled nutritive drink, they were asked to score the sample on a scale

Table 2
The relationship between score and concentration of standard solution (unit: mmol/L)

Score	Sweetness, sucrose	Saltiness, sodium chloride	Sourness, tartaric acid	Bitterness, quinine sulfate
1	29.2	20.5	0.17	0.003
2	87.7	51.3	0.6	0.012
3	181.7	130.0	1.73	0.031
4	409.4	273.8	4.66	0.078
5	994.2	616.0	11.99	0.201

Table 3
Gustatory sensation test sheet used in the present study

Product							
		Extremely 1	Slightly 2	Neither 3	Slightly 4	Extremely 5	
Q1	Not pungent						Pungent
Q2	Not astringent						Astringent
Q3	Not fruity						Fruity
Q4	Weak taste of medicinal plant						Strong taste of medicinal plant
Q5	Not irritating to throat						Irritating to throat
Q6	Not refreshing						Refreshing
Q7	Does not seem beneficial						Seems beneficial
Q8	No aftertaste						Strong aftertaste
Q9	Do not want to drink again						Want to drink again
Q10*	Difficult to drink						Easy to drink

*Overall palatability.

of 1–5 for the four basic tastes (sweetness, saltiness, sourness, and bitterness), for overall palatability, and for nine components of palatability (astringency, pungency, fruitiness, tasting of a medicinal plant, refreshing, irritating to the throat, seeming beneficial, good aftertaste, and the desire to drink again) (see Table 3). All samples were kept in the mouth for 10 s. After tasting each sample, subjects gargled well and waited for at least 20 min before testing the next sample.

Table 4
Lipids component used this study

Channel	Lipid component
1	Phosphoric acid di-*n*-decyl ester Dioctyl phenyl-phosphate
2	Phosphoric acid di-*n*-decyl ester 2-Nitrophenyl octyl ether
3	Hexadecanoic acid Dioctyl phenyl-phosphonate
4	Dioctyl phenyl-phosphonate
5	Tetradodecylammoniumbromide Dioctyl phenyl-phosphonate
6	Tetradodecylammoniumbromide 2-Nitrophenyl octyl ether
7	Dioctyl phenyl-phosphonate Phosphoric acid di-*n*-hexadecyl ester Tetradodecyl ammoniumbromide
8	Tetradodecyl ammonium bromide Tetradecyl alcohol Dioctyl phenyl-phosphonate

2.3. Sensor measurement and data analysis

The taste-sensing system SA402 of Intelligent Sensor Technology Co. Ltd., Atsugi, Japan, was used in the evaluation. The detecting sensor part of the equipment consists of eight electrodes composed of lipid/polymer membranes. The lipid components of the sensor, shown in Table 4, are the same as those described in a previous paper (Uchida et al., 2003). Samples of the nutritive drinks were mixed with 10 mmoL/L potassium chloride to produce solutions for evaluation. S-PLUS 2000J (Mathematical Systems Inc., Tokyo, Japan) was used for regression analysis.

3. Results and discussion

3.1. Relation between overall palatability and the four basic tastes

Table 5 shows the relationship between the overall palatability score and four basic tastes (sweetness, saltiness, sourness, and bitterness). The actual correlations for the 20 products are shown in Fig. 1. There was a high correlation between the sourness of the drinks and overall palatability ($r = 0.79$). This result supports the finding of Miyanaga et al. (2003) that sourness increases palatability.

A clear negative correlation was found between overall palatability and bitterness ($r = -0.76$), as shown in Fig. 2. Three of the medium/high-price group

Table 5
Relationship between overall palatability and four basic intensities and individual palatability

Correlation with palatability	
Sweetness	0.39 ($P < 0.100$)
Sourness	0.79 ($P < 0.001$)
Bitterness	−0.76 ($P < 0.001$)
Saltiness	−0.30 ($P < 0.500$)
Pungency	−0.50 ($P < 0.005$)
Astringency	−0.39 ($P < 0.050$)
Fruity	0.85 ($P < 0.001$)
A feeling of medicinal plant	−0.74 ($P < 0.001$)
Refreshing	0.74 ($P < 0.001$)
Irritation to throat	−0.58 ($P < 0.010$)
Seems to be beneficial	−0.62 ($P < 0.050$)
Good aftertaste	0.70 ($P < 0.010$)
Want to drink again	0.93 ($P < 0.001$)

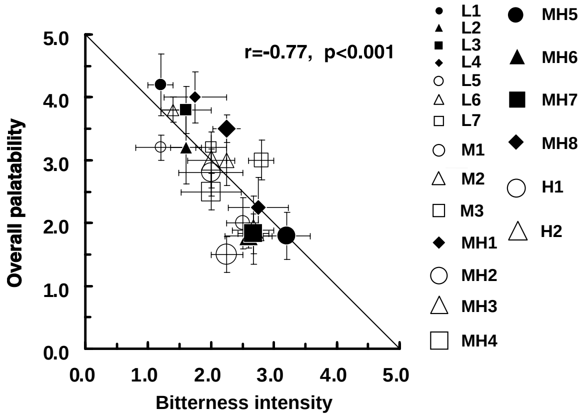

Fig. 2. Relationship between overall palatability and bitterness intensity. The obtained overall palatabity score and bitterness intentity were represented as the mean ($n = 7$) plus standard error. The standard bitterness score and corresponding concentration of quinine solution were shown in Table 2.

products (MH5, MH1, MH7) and two high-price group products (H1, H2) had the greatest bitterness intensity. This negative correlation between overall palatability and bitterness intensity is not unexpected. Overall palatability was not found to correlate with sweetness ($r = 0.39$), since the relation does not reach statistical significance. The actual correlation data are shown in Fig. 3. Most of the products were in the sweetness intensity range of 2.0–3.0.

The highly priced products tended to have comparatively lower overall palatability scores. This is probably due to the fact that these products contain higher concentrations of various components with a bitter taste (such as the active ingredients of medicinal plants) or with high pungency (such as capsaicin). Increasing the sweetness of a product is not always able to mask completely the unpleasant taste caused by bitterness or pungency, or sometimes even the smell of these components. On the contrary, the

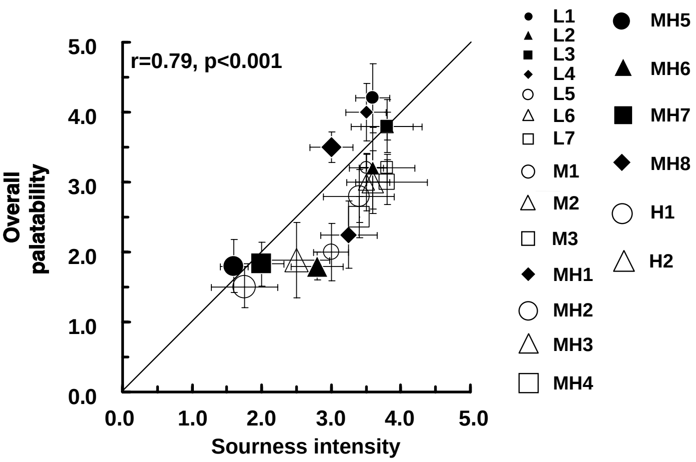

Fig. 1. Relationship between overall palatability and sourness intensity. The obtained overall palatabity score and sourness intentity were represented as the mean ($n = 7$) plus standard error. The standard sourness score and corresponding concentration of tartaric solution were shown in Table 2.

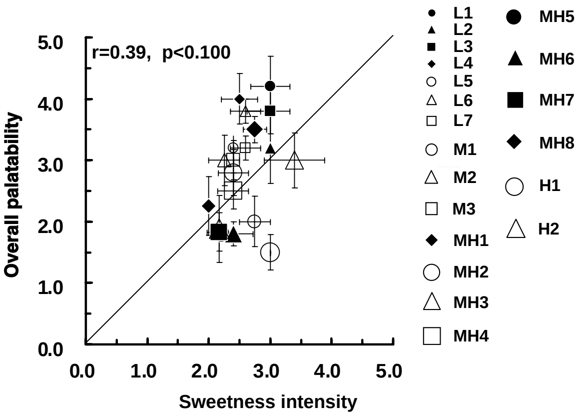

Fig. 3. Relationship between overall palatability and sweetness intensity. The obtained overall palatabity score and sweetness intentity were represented as the mean ($n = 7$) plus standard error. The standard sweetness score and corresponding concentration of sucrose solution were shown in Table 2.

addition of too much sweetener to a product may decrease the overall palatability due to the strong, sweet, aftertaste.

All the nutritive drinks had a similar value for saltiness and the correlation with overall palatability, although negative, was low ($r = -0.30$; data not shown).

3.2. Relationship between overall palatability and nine components of palatability

The correlation between the overall palatability score and the nine components of palatability was examined. A high palatability is essential for bottled nutritive drinks if they are to be consumed on a daily basis in the same way as beverages such as fruit juices. The correlation with 'fruitiness' was the highest ($r = 0.85$), but positive correlations were also found between the overall palatability score and the scores for 'refreshing' and 'good aftertaste' ($r = 0.74$ and 0.70, respectively) as shown in Table 5. These components are presumed to result from the 'sour' organic acids contained in the drinks, since sourness was positively correlated with overall palatability.

On the other hand, the palatability components 'tasting of a medicinal plant', and 'seeming beneficial' showed a negative correlation with overall palatability ($r = -0.76$ and -0.62, respectively). This finding suggests that the smell or bitterness resulting from a relatively high content of vitamins and medicinal plant ingredients might negatively influence the overall palatability of the drinks. The items 'irritating to throat' and 'pungency' were also negatively correlated with overall palatability ($r = -0.58$ and -0.50). The item 'desire to drink again' was closely related to the overall palatability, as expected ($r = 0.93$).

Drinks in the low-price group had comparatively higher overall palatability scores than those in the higher price groups (Figs. 1 and 2), although their sweetness scores were only between 2 and 3 on the standard solution score. These drinks tended to have a higher content of organic acids such as citric acid (or fruit-type flavours containing organic acids), which may reduce their bitterness and/or mask the smell arising from the inclusion of vitamins.

The products from the medium/high- and high-price groups had comparatively high scores for 'seeming beneficial' but low overall palatability scores. In particular, products containing higher concentrations of active ingredients from medicinal plants (used for patients with tired eyes and stiff shoulders) had lower overall palatability due to their bitter taste and unpleasant smell.

3.3. Prediction of four basic tastes and overall palatability by the taste sensor

The ability of the artificial taste sensor to predict the intensities of sourness, bitterness and pungency, as well as overall palatability, was examined for all 20 drinks. The ability of the taste sensor to predict the intensities of sweetness or saltiness was not examined, as these basic tastes did not show a correlation with overall palatability in this study.

3.3.1. Prediction of sourness by taste sensor

The sourness of the bottled nutritive drinks is assumed to be due to the content of an organic acid (e.g., citric acid, DL-malic acid, or tartaric acid). All the products from the low-price group (L1–L7), and three from the middle (M1, M2) and middle/high-price group (MH1) have comparatively low pH values (around or under 3). These products have a comparatively high content of organic acids. This is evidenced by the output (relative value) observed in channels 5–8 of the sensor, with negative charges caused by the

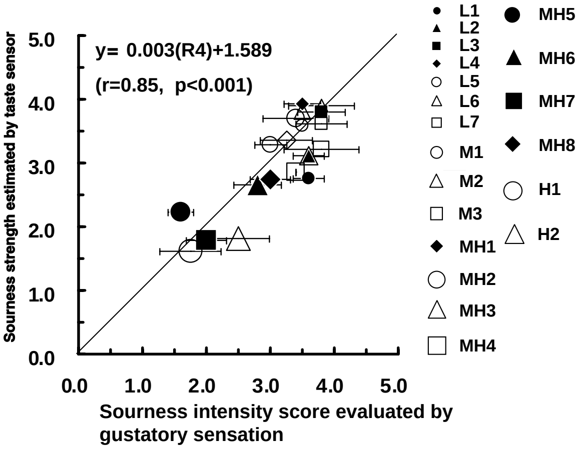

Fig. 4. Relationship between sourness intensity scores obtained in human gustatory tests and those predicted by the taste sensor. The obtained value was represented as the mean ($n = 7$) plus standard error. The standard sourness score and corresponding concentration of tartaric solution were shown in Table 2. In figure, R4 means the relative value of channel 4.

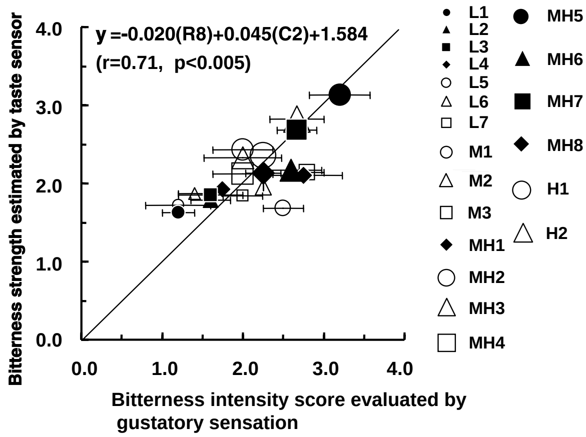

Fig. 5. Relationship between bitterness intensity scores obtained in human gustatory tests and those predicted by the taste sensor. The obtained value was represented as the mean ($n = 7$) plus standard error. The standard bitterness score and corresponding concentration of quinine solution were shown in Table 2. In figure, R8 and C2 mean the relative value for channel 8 and CPA value for channel 2, respectively.

carboxyl group. However, a stronger output was observed in channels 1–4, arising from protons released by the carboxyl group. The output from channel 4 shows the highest correlation ($r = 0.851$) with the sourness intensity score obtained from human gustatory sensation tests, which varied from 1.5 to 4.0, and is shown in Fig. 4.

The products with a higher content of medicinal plant ingredients (M3 and MH2–4) had higher sourness scores, while the higher priced products, and those indicated for use in patients with tired eyes and stiff shoulders (MH5–8), tended to be considerably less sour.

3.3.2. Prediction of bitterness intensity

In the evaluation of the bitterness of medicines, the sensor relative output values (R) and the CPA (change of membrane potential caused by adsorption) values of channels 1–4 were used to predict bitterness (Uchida et al., 2000). In the present study, however, the relative value of channel 8 and the CPA value of channel 2 were used to predict bitterness, as shown in Fig. 5. This resulted in a comparatively good correlation ($r = 0.708$) between the sensor data and the bitterness intensity data from the human gustatory sensation tests. Products from the low-price product group were less bitter than products indicated for use in patients with tired eyes and stiff shoulders. Product MH5 was the most bitter; this is likely to be due to its relatively high content of thiamin and derivatives.

3.3.3. Prediction of pungency score

The taste sensor has previously been used to evaluate the basic tastes (bitterness, saltiness, sweetness, and sourness, and also the sweet–savoury taste known as *umami* (from the Japanese *umai*, meaning delicious). There have been few reports, however, on the evaluation of pungency, such as that caused by capsaicin (Iiyama et al., 1994).

In the present study we therefore attempted to evaluate pungency in gustatory sensation tests, and to determine whether or not the ‘pungency score’ derived from these tests could be predicted by taste sensor measurement. Multiple regression analysis was adopted because there are no specific lipid components to evaluate pungency to capsaicin. It was found that pungency could be predicted using data from channels 1, 5, and 8, as shown in Fig. 6. (In general, channel 1 responds to bitterness, such as quinine or amino acids, channel 5 responds to astringency, such as the tannic acids in tea, and channel 8 responds to saltiness.) Using these data, a comparatively good

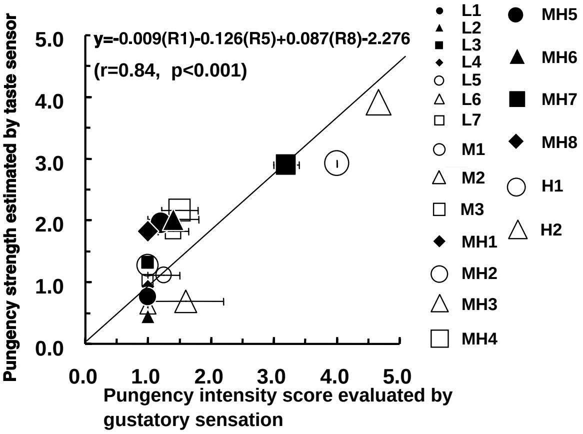

Fig. 6. Relationship between pungency intensity scores obtained in human gustatory tests and those predicted by the taste sensor. The obtained value was represented as the mean ($n = 7$) plus standard error. R1, R5 and R8 values mean the relative values for channels 1, 5, and 8, respectively.

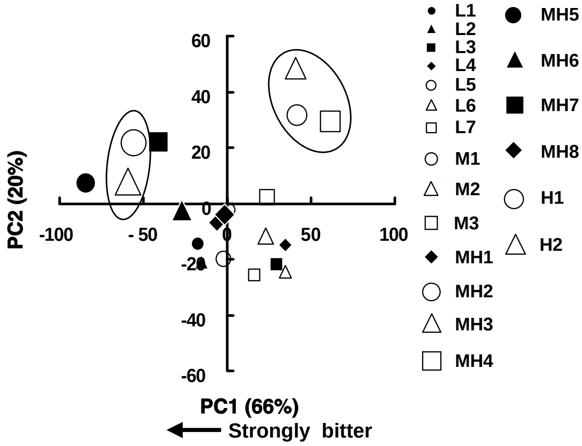

Fig. 7. Principal component analysis of taste sensor data from commercially available bottled nutritive drinks. The relative contribution of PC1 and PC2 were calculated to be 66 and 20%, respectively. For further, explanation, see text.

correlation ($r = 0.844$) was found between the predicted pungency and that obtained in human gustatory sensation tests. Three of the bottled nutritive drinks, MH7, H1 and H2, contained capsaicin (from Capsicum). The pungency of these products was considerably greater than that of the other 17 products.

3.4. Principal component analysis of sensor data

We performed a principal component analysis of the data for the 20 drinks using the relative values (R) of sensor output from channels 1–6 and 8, and CPA values from channels 2, 5, 6, 7, and 8, as 12 explanatory valuables. The results are shown in Fig. 7. The relative contributions of PC1 and PC2 are 66 and 20%, respectively. Factor PC1 can be assumed to represent bitterness intensity. The identification of PC2 shows that there is an additional taste quality, distinct from bitterness, which is quite different in products from the different price groups, and in products containing medicinal plant ingredients in the middle/high and high-price groups. This latter group of products have a different quality of taste than the other middle/high-price group products. Product MH7, a drink indicated for use in patients with tired eyes and stiff shoulders, resembled these products in this respect.

4. Conclusions

Human gustatory sensation tests on 20 bottled nutritive drinks commercially available in Japan revealed a positive linear correlation between scores for overall palatability and those for ‘sourness’, ‘fruitiness’, ‘refreshing’, and ‘good aftertaste’. There was a negative correlation between scores for overall palatability and those for ‘bitterness’, ‘tasting of a medicinal plant’, ‘seeming beneficial’, and ‘pungency’.

There was a good correlation between the results of human gustatory sensation tests and taste sensor data for sourness and bitterness, and the palatability component pungency. Principal component analysis of taste sensor data showed that the products could be grouped according to differences in the quality of taste, and that this was related to the price class of the products. Low-price group products showed high overall palatability, and this correlated well with their scores for ‘fruitiness’, ‘sourness’, and ‘refreshing’. These nutritive drinks contained fruit flavours whose sourness was effective in increasing overall palatability.

It was possible to predict the taste of bottled nutritive drinks comparatively easily using the taste sensor. In addition, it was possible to differentiate between low-price group products, products containing ingredients from medicinal plants in the middle/high-price group, and high-price group products containing ingredients from medicinal plants.

In conclusion, the taste sensor may play a useful role in evaluating the palatability of bottled nutritive drinks.

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