Quantitative expression of mixed taste of amino acids using multichannel taste sensor

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Amino acids with different functional group show different taste such as bitterness, sweetness and umami. Some of them elicit complicated mixed taste; e.g., L-methionine tastes bitter and sweet simultaneously. A multichannel taste sensor using lipid membranes was applied to amino acids. It was shown that bitter amino acids such as L-tryptophan have response electric patterns similar to a typical bitter substance, quinine, that belongs to alkaloids. The response pattern for L-methionine was found to be similar to that for a mixed solution composed of a sweet amino acid (L-alanine) and bitter amino acid (L-tryptophan). These results agreed quantitatively with human sensory evaluations.

Keywords: taste sensor, amino acids, mixed taste, quantification, lipid membranes

1. INTRODUCTION

Amino acids are so important that they produce taste in various kinds of foods, typically, fermented foods such as beer and wine. Each of amino acids elicits complicated mixed taste itself; e.g., L-methionine produces sweet and bitter tastes at the same time. Here we show the quantification of the taste of amino acids using artificial sensing device.

Odor sensors (i.e., electronic noses) are studied vigorously in recent days. They utilize sensing devices such as quartz oscillator, metal oxide gas sensor, conducting polymer, gas-sensitive field-effect device for transforming information of chemical substances into electric signals.

A multichannel taste sensor, i.e., electronic tongue, with global selectivity is composed of several kinds of lipid/polymer membrane for transforming information of taste substances into electric signals, which are input to a computer. The sensor output shows different patterns for chemical substances that have different taste qualities such as saltiness and bitterness, while it shows similar patterns for chemical substances with similar tastes. The taste sensor can detect and quantify taste interactions such as suppression effect that appears between sweetness or saltiness and bitterness. In the present paper, the mixed taste elicited by amino acids such as L-methionine is expressed quantitatively using the taste sensor by combination of basic taste qualities elicited by L-alanine (L-ala) and L-tryptophan (L-trp), which taste purely sweet and bitter, respectively.

2. MATERIALS AND METHODS

The transducer of the multichannel taste sensor is composed of lipid membranes immobilized with a polymer. Eight kinds of lipid analogue are used for preparing the membranes, as reported previously. Lipids used are summarized in Table 1. The major parts of the functional groups in the biological membranes are lined up with these lipids. Two kinds of lipids were mixed in a given molar ratio in chs. 4-6. Each lipid was mixed in a test tube with polyvinyl chloride (PVC) and a plasticizer (dioctyl phenylphosphonate, DOPP), which were dissolved in tetrahydrofuran. Successively, the mixture was dried in a glass plate, which was placed on a hot plate controlled at about 30°C. The lipid/polymer membrane thus prepared was a transparent, colorless and soft film with about 200 μm thickness.

The measurements were made using a taste-sensing system, SA402 (Anritsu Corp.), shown in Fig. 1. Each membrane was fitted at the part of a plastic tube, which contains a hole, such that the inner part of the cylinder was isolated from the outside, as shown in Fig. 2. The other end of the cylinder was sealed with a stopper that holds an Ag/AgCl wire electrode. The tube was filled with 3 M KCl, saturated AgCl solution. Eight electrodes were separated to two groups of chs. 1-4 and chs. 5-8; four electrodes and a reference electrode were fitted in an electrode holder. Two electrode holders thus prepared were controlled by a robot arm, and the out-

Table 1. Lipid materials used in the multichannel electrode.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Lipid (abbreviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n-Decyl alcohol (DA)</td>
</tr>
<tr>
<td>2</td>
<td>Oleic acid (OA)</td>
</tr>
<tr>
<td>3</td>
<td>Dioctyl phosphate</td>
</tr>
<tr>
<td>4</td>
<td>DOP : TOMA = 9 : 1</td>
</tr>
<tr>
<td>5</td>
<td>DOP : TOMA = 8 : 1</td>
</tr>
<tr>
<td>6</td>
<td>DOP : TOMA = 3 : 7</td>
</tr>
<tr>
<td>7</td>
<td>Triocyl methyl ammonium chloride (TOMA)</td>
</tr>
<tr>
<td>8</td>
<td>Oleyl amine (OAm)</td>
</tr>
</tbody>
</table>
3. RESULTS

Figure 3 shows the comparison of response patterns of three amino acids (L-alanine, L-tryptophan, L-phenylalanine) with those of a bitter substance (quinine), sour substance (HCl) and umami taste substance (monosodium glutamate, MSG). Three normalized patterns are shown for one chemical substance with three different concentrations. Each response pattern is average of three measurements. Typical values of relative standard deviations were 0.20, 0.22 and 0.06% in chs. 3, 5 and 7, respectively, for 10 mM L-tryptophan. These values are of the same order or smaller than those reported previously[11]. The response patterns were normalized using the formula: \( v_i = V_i / \sqrt{\sum |V_i|^2} \), where \( V_i \) denotes the response electric potential of channel \( i \), and the summation is made over \( i = 1 - 8 \). To make it easy to see the pattern, the response electric potentials of the positively charged membranes (chs. 6–8 in Table 1) and the noncharged membrane (ch. 5) were reversed, because they usually have a sign opposite to those of the negatively charged membranes (chs. 1–4). The reversed channels are designated by symbols such as OAm- and TOMA- in Fig. 3.

The three patterns of each chemical substance agree with each other; i.e., we get the pattern independent of the concentration. This fact implies that each chemical substance has an original pattern characteristic of each taste quality. The patterns of amino acids such as L-tryptophan and L-phenylalanine are similar to that of quinine. However, they differ from those of other taste substances such as L-alanine, HCl and MSG.

The patterns for L-tryptophan and L-phenylalanine, which taste bitter, bulge out to the upper-right direction (i.e., at chs. 1–3), whereas the pattern for L-alanine, which tastes sweet, shows the opposite tendency; i.e., its pattern bulges out to the lower-left direction. The bitter chemical, quinine, shows a bulge to the upper-right direction in a similar way to L-tryptophan.
The correlation coefficients between L-tryptophan (10 mM) and five basic taste substances are as follows: 0.903 for 0.3 mM quinine, 0.276 for 30 mM NaCl, 0.763 for 3 mM HCl, 0.408 for 100 mM sucrose and 0.408 for 10 mM MSG. Although L-tryptophan has low correlations with salty (NaCl), sweet (sucrose) and umami (MSG) substances, it has a high correlation with a bitter substance, quinine. This result indicates that L-tryptophan shows the same taste as quinine.

Comparison of the original response pattern of L-tryptophan with that of quinine makes it possible to estimate the bitter strength of L-tryptophan in terms of the quinine concentration using multivariate analysis (13). As a result, it was concluded that 10 mM L-tryptophan has the same bitter strength as 0.02 mM quinine.

The sensory evaluation was performed using our tongue. The result supported the estimation using the taste sensor. The same bitter strength as 10 mM L-tryptophan was felt by taking 0.02-0.03 mM quinine, because four persons assessed 0.02 mM quinine, five persons 0.03 mM quinine and one person 0.1 mM quinine. This result suggests that the taste sensor measures the taste in itself, irrespective of the difference of chemical structures of amino acids and alkaloids such as quinine.

Next, we tried to produce the complicated mixed taste of amino acids such as L-methionine and L-valine using the combination of a sweet amino acid, L-alanine, and a bitter amino acid, L-tryptophan. Figure 4 shows the normalized patterns for L-methionine and the mixed solution, which contains 100 mM L-alanine and L-tryptophan with three different concentrations of 1, 3 and 10 mM. Three patterns for L-methionine with three different concentrations agree fairly well with each other. Although the response pattern for 10 mM L-methionine differs slightly from the other two, it may correspond to a slight change of taste quality with change in the concentration (4)(5). In addition, they differ from those for L-alanine and L-tryptophan shown in Fig. 3, as found in Table 2. For example, 10 mM L-methionine has the correlations of 0.22 and 0.57 with 10 mM L-alanine and 1 mM L-tryptophan, respectively. This implies that L-methionine has its original taste quality, different from pure sweet or bitter taste.

The patterns for the mixed solution composed of 100 mM L-alanine and L-tryptophan with three different concentrations do not agree with each other. Increase in the L-tryptophan concentration tends to show the pattern that bulges to the upper-right direction. Since the pattern for L-tryptophan has a characteristic of bulge to the upper-right direction, it implies that the taste of mixed solution becomes nearer that of L-tryptophan, as expected.

Table 2 summarizes the correlation coefficients among L-methionine, L-alanine, L-tryptophan and the above three mixed solutions. The response patterns for L-alanine have negative correlations with those for L-tryptophan. It agrees with the fact that they show much different taste qualities.

Increasing L-tryptophan concentration in the mixed solution leads to both the decrease of correlation with L-alanine and the increase of correlation with L-tryptophan, as considered reasonably. We can see that the highest correlation is realized between one of the mixed solutions and L-methionine. The highest correlation 0.99 is realized for 30 mM L-methionine using the mixed solution of 100 mM L-ala + 10 mM L-trp. The sensory tests by humans agreed with this result. Seven persons felt the same quality as 30 mM L-methionine for 100 mM L-ala + 10 mM L-trp, while two persons assessed 100 mM L-ala + 3 mM L-trp, one person 100 mM L-ala + 1 mM L-trp.
4. DISCUSSION

In the present paper, it was shown using the multichannel taste sensor that bitter amino acids, L-tryptophan and L-phenylalanine, show response electric patterns similar to a typical bitter substance, quinine. The bitter strength of L-tryptophan was quantified, and the result agreed with the human sensory evaluation. It was found that L-methionine, which tastes bitter and sweet simultaneously, has the same response pattern of the mixed solution composed of L-alanine and L-tryptophan with adequate composition, as seen from the high correlation of 0.99. This result was also supported by the human sensory evaluation.

It is believed physiologically that receptors of amino acids differ from those of alkaloids such as quinine. As found here, however, the bitterness of amino acids can be expressed using the response patterns of the taste sensor, which uses the lipid membranes, in a way similar to the bitterness of quinine. The mixed taste of amino acids can also be reproduced using the taste sensor. The present results suggest a possibility that amino acids and alkaloids which taste bitter are received at the same part of biomembrane.

Recently, miniaturization and integration of taste sensor using lipid membranes have been tried (17) (18). This kind of approach may increase the feasibility of taste sensor for application to real-time measurements of chemical substances in organism as well as foodstuffs.

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References


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Taste of Amino Acids using Taste Sensor