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Comparison of Taste of Amino Acids and Basic Taste Substances Using Surface-Polarity Controlled Sensor

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Abstract: In order to analyze the taste quality of amino acids, basic taste substances were studied using the surface-polarity controlled sensor. The sensor outputs showed different potential profile patterns for basic taste substances that have different taste qualities, while it showed similar patterns for amino acids which have similar taste. However, all amino acids used in the analysis had a basic peak around 0.1 V due to a basic amino group (**NH_2**) in the amino acid molecules. Therefore, in order to compare the taste quality of amino acids with that of basic taste substances, a basic peak around 0.1 V of amino acids was eliminated by a curve fitting analysis. With the result, the taste quality of amino acids could be classified into four groups according to that of basic taste substances.

Keywords: Amino acids, Surface-polarity, Potential profile, Taste quality, Curve fitting

1. Introduction

Amino acids that are required for protein synthesis and cannot be synthesized by the organism must be present in the diet. Not all amino acids can be obtained by interconversions from other amino acids or by synthesis from other compounds in the animal system. Such compounds are referred to as essential amino acids and are usually considered essential for humans. Only twenty amino acids are commonly found in plant and animal proteins. The amino acids found in proteins are α-aminocarboxylic acids. Variation in the structures of these monomers occurs in the side chain. The structural formula of amino acids is shown in **Fig.1**.

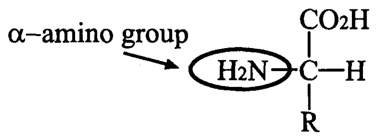

Fig.1 The structure of amino acids.

The simplest amino acid is aminoacetic acid, called glycine, which has no side chain and consequently does not contain a chiral carbon. All other amino acids have side chains, and therefore their α-carbons are chiral. An amino acid contains a basic amino group (**NH_2**) and an acidic carboxyl group (**COOH**) in the same molecule. Amino acids have side chains (**R**), and they determine whether the amino acids are acidic, basic or neutral. This is the reason why amino acids produce different characteristics and tastes.

The taste of amino acids was studied using the taste sensor.[1-4] Each of amino acids elicits complicated and mixed tastes. Amino acids are generally classified into several groups that correspond to each characteristic taste. In the previous study we studied the taste of amino acids using the surface-polarity controlled sensor.[5] The taste of amino acids presented in the paper was classified into four groups in accordance with the sensor outputs.[5] However, all potential profiles formed from amino acids had a basic peak around 0.1 V due to α-amino group (**NH_2**), which was not formed in case of basic taste substances such as HCl, NaCl, sucrose and quinine. So the amino acids could not be classified into the same region generated by other typical basic taste substances. Thus, a comparison of the taste quality of amino acids and basic taste substances was needed in taste sensor applications. Because of the presence of a basic peak around 0.1 V, it was difficult to induce the relationships between the taste quality of amino acids and basic taste substances.

In the present paper we compare the taste quality of amino acids with basic taste substances from the point of view of response patterns obtained by surface-polarity controlled sensor. In order to compare the taste quality of amino acids with that of basic taste substances, the basic peak of amino acids was eliminated by means of a curve fitting analysis and we aimed at evaluation of their taste with sen-

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sor outputs of basic taste substances.

2. Materials and Methods

2.1 Chemical Substances

All five basic taste substances used in the experiments were of analytical grade and employed without further purification. Five taste substances producing the five typical tastes, i.e., HCl (sourness), NaCl (saltiness), quinine·HCl (bitterness), sucrose (sweetness) and monosodium glutamate (MSG, umami taste) were used. All amino acids used in the experiments were L-type and employed without further purification. All chemical taste substances used in the experiments were dissolved in water containing 10 mM KCl prior to the experiments.

2.2 Electrode preparation

The working electrode was made by inserting the 1 mm Pt wire into an acrylic board with a 5 mm diameter hole. The hole was filled with epoxy resin. The Pt wire was polished using sandpaper and 0.1 μm alumina polishing suspension until the surface became smooth.

The reference electrode composed of an Ag/AgCl wire with saturated KCl solution and a counter electrode used in the experiments was a 1 mm diameter Pt wire. **Figure 2** shows a simplified diagram of electrodes used in the experiments.

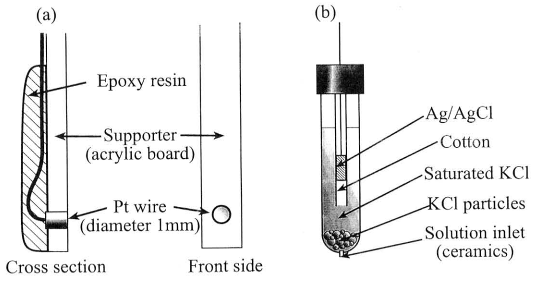


Fig.2 The working electrode (a) and the reference electrode (b).

2.3 Measurements

A recently developed surface-polarity controlled sensor has a higher and better reproducibility than that of the human sense.[5] In the present study, in order to compare the taste quality of amino acids with that of five basic taste substances, we measured basic taste substances with the same method which had studied the taste of amino acids using this sensor.[5] The apparatus setup used in the measurements of taste substances and equivalent circuit were shown in **Fig.3**.[5]

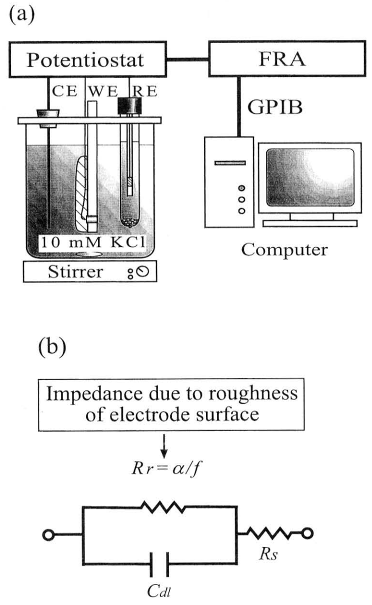


Fig.3 Setup for the measurement of the electrode impedance (a) and equivalent circut (b). WE : working electrode, RE : reference electrode, CE : counter electrode.

The equivalent circuit consists of the connection in parallel of the electrode resistance (R_r) and the electrode capacitance (C_{dl}) of the electrical double layer on the electrode surface. The term R_r is the unusual electrical resistance caused by roughness of the electrode surface, where the resistance depended on frequency which is f; $R_r = \alpha/f$ where α is constant. The solution resistance (R_s) is connected in series to the parallel connection of R_r and C_{dl}. We carried out curve fitting on the frequency response locus to obtain the resistance and capacitance of the electrode.

R_{45} and C_{dl} which were the responses of the interface impedance were measured by setting the response to 10 mM KCl solution as the origin. The term R_{45} is the estimated value of R_r at $f = 45$Hz. The changes of R_{45} and C_{dl} by addition of taste substances were ΔR_{45} and ΔC_{dl}, respectively.

Using this measuring system, we measured the electrode impedance changes with the electrode potential changes and regarded the change of a pattern as the potential profile. All measurements and data analysis were conducted using macro programs on IgorPro (Wavemetrics Inc.). The measurements were carried out under room temperature.

3. Results

3.1 Response Patterns to Five Basic Taste Substances

The electrode potential profiles for five basic taste substances producing the five typical basic tastes were shown in **Fig.4**. The electrode potential profiles were clearly discriminated from each other; for example the electrode potential profile of sucrose which is a sweet substance increased toward the right-upper direction, whereas the response of quinine·HCl which is a bitter substance was the opposite direction to that of sucrose.

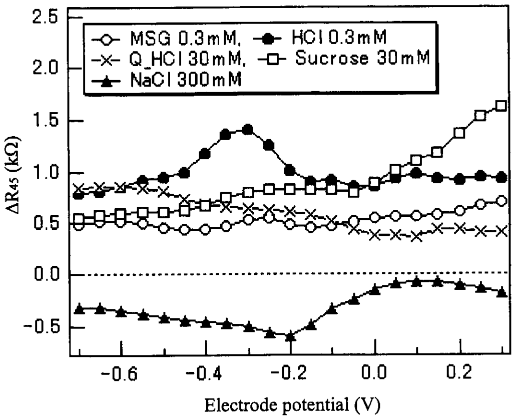


Fig.4 The electrode potential profiles for five basic taste substances.

The patterns of HCl and NaCl which produce sour and salty taste, respectively, were clearly different from those for other substances. The pattern of NaCl had a peak around −0.2 V, and had a smooth curve around 0.1 V as shown in **Fig.4**. This response pattern was the opposite to that of 10 mM KCl standard solution which had a peak around −0.2 V and a curve around 0.1 V.[5] The resistance of the electrode surface was decreased by NaCl and thereby decreasing the electric potential dependency of the electrode.

As seen above, the potential profile patterns of the electrode impedance for substances producing different taste qualities were much different, and hence each taste could be easily discriminated. Furthermore, various chemicals, which have similar taste quality of typical basic taste, elicit similar response patterns. These results implied that the taste quality was distinguishable using the response patterns constructed from the surface-polarity controlled sensor. In addition, the order of sensitivities for used taste chemicals was the same and had a good correlation to that of human gustation. Therefore, it is possible that this taste sensor has an ability to respond to the taste itself.

3.2 Analysis of Amino Acid Responses Using a Curve Fitting

Figure 5 shows the electric potential profiles (ΔR_{45}) obtained from alanine (Ala), histidine (His), glutamic acid (Glu) and monosodium glutamate (MSG) which are the representatives of sweet, bitter, sour and umami substances of amino acids, respectively. As seen from **Fig.5**, different potential profiles of the sensor outputs were obtained for different tastes such as sweet, bitter, sour and umami-tasting amino acids, but similar patterns were obtained for similar taste amino acids. The electrode capacitance patterns did not differ very much between amino acids used in the data analysis. Consequently, we discussed taste responses mainly of ΔR_{45}.

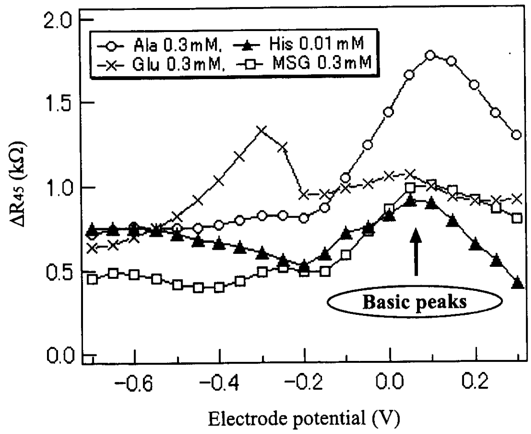


Fig.5 The electrode potential profiles for Ala, His, Glu and MSG.

A peak around 0.1 V was brought about by a basic amino group (**NH$_2$**) bonded to the α-carbon atom in the amino acid molecules and it could be seen all amino acids used in the analysis as shown in **Fig.5**, whereas the peak was not seen for other basic taste substances (**Fig.4**).

Therefore, in order to compare the taste quality of amino acids with that of five basic taste substances, in the same manner the peak around 0.1 V of all amino acids have to be eliminated through a data analysis of a curve fitting. To get rid of a peak from the original data of amino acids, the Gaussian curve fitting was used. There is no premising knowledge on potential profile patterns of the electrode impedance, so we chosed the Gaussian.

The synthetic data was generated using a Gaussian function as shown in **Fig.6**. The elimination procedures of the peak around 0.1 V of amino acids are as follows.

- Fitting a straight line (y) through the original curve (A) with equation (1) to remove linear trend in response patterns.
- *Res_Curve* (B) which is the difference between straight line and the original data added to coefficient a of straight line makes curve C.
- Fitting was conducted using a Gaussian curve with equation (2) to a part to be eliminated in curve C.
- *Res_Curve* (D) which is the difference between curve (C) and Gaussian curve (G) added to straight line (y) makes resulted curve (S), whose a peak around 0.1 V is eliminated.

The curve fitting function was given by:

$$y = a + bv, \tag{1}$$

$$G = Y_0 + A\exp\left[-\left(\frac{v - V_0}{width}\right)^2\right], \tag{2}$$

where Y_0, A, v and V_0 are the baseline, the amplitude, the electrode potential and the position in Gaussian curve, respectively as shown in **Fig.6(b)**. Using above method, we eliminated the peak around 0.1 V of all amino acids and regarded the synthetic data as the taste qualities of amino acids.

3.3 Response Patterns to Amino Acids Cancelled the Basic-Peak

In **Fig.7**, the potential profiles of the sensor due to four chemical substances were compared with the patterns of amino acids obtained by the method explained in section 3.2.

It could be clearly seen that the patterns for amino acids were different from each other. As seen from **Fig.7**, the different potential profiles were obtained for substances which have different taste such as sweet, bitter, sour and umami-taste amino acids and the similar patterns could be obtained for similar taste. This implies that the taste of amino acids can be measured qualitatively by this method and may be explained by interactions based on electrode polarity. For example, the patterns of amino acids which produce sweet taste increased toward the right-upper direction like that of sucrose which is a sweet substances, whereas the patterns of amino acids which produce bitter taste was the opposite direction to that of sweet amino acids. Umami substances, MSG and AspNa shown similar patterns also. Although they were not very different from sweet substances, they were easily discriminated because their patterns had a gentle slope compared with those of sweet amino acids.

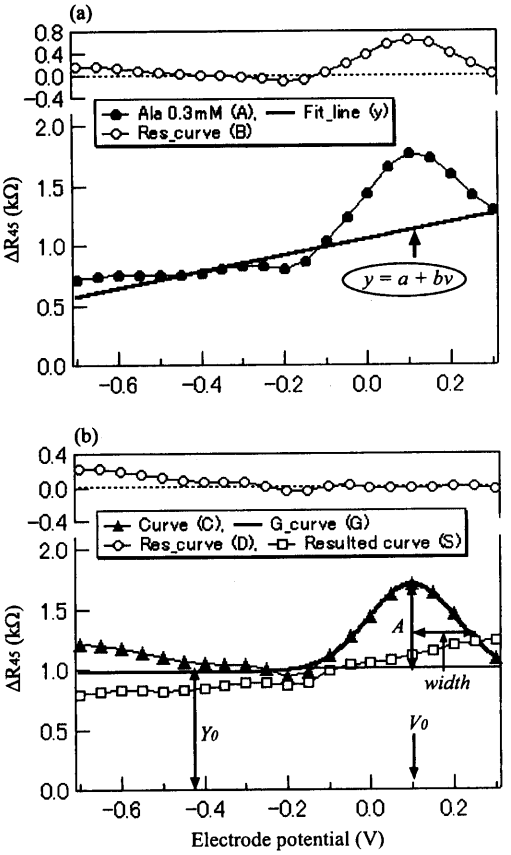
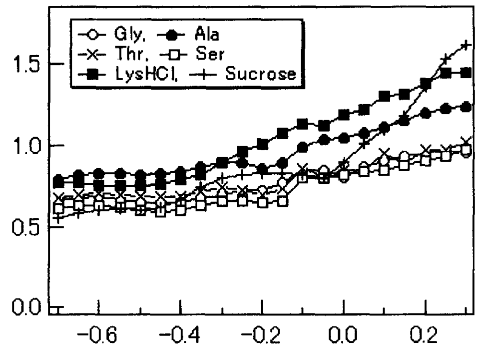


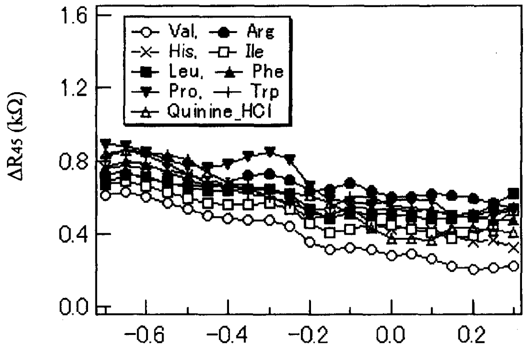
Fig.6 Elimination procedures of the peak around 0.1 V for Ala which is sweet amino acid.

Glu, Asp and HCl which produce sour taste had a peak around −0.3 V. Because these three substances generate a hydrogen ion in solution, it was possible that this peak mainly depended on adsorption and desorption of hydrogen ions around −0.3 V. When the reference electrode is saturated KCl/Ag-AgCl electrode, adsorption and desorption of hydrogen ions by the Pt-electrode occur around −0.3 V of electrode potential.[6] It was a property that came out only sour taste substances, and was more clearly different from those for other substances. As noted above, it was possible that amino acids could be expressed as a combination of taste of four chemical substances.

(a) Sweetness



(b) Bitterness



(c) Sourness and umami

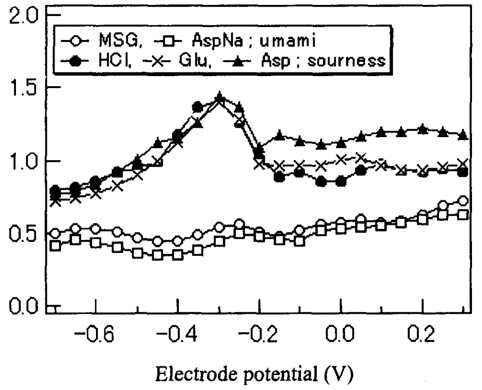


Fig.7 Comparison of four chemical substances and amino acids eliminated a basic peak by a curve fitting.

3.4 Principal Components Analysis

In **Fig.8** the data of amino acids eliminated the peak around 0.1 V and four basic taste chemical substances were visualized on the two-dimensional plane using principal components analysis (**PCA**), which is a kind of multivariate analysis and is very effective in reducing the dimensional space with minimum loss of information.[7] **Figure 8** shows the data points plotted in a scatter diagram obtained by the **PCA**. The **PCA** was made here using the variance and covariance matrices. The contribution rates were 79.88% 15.65% 2.89% for PC1, PC2 and PC3, respectively.

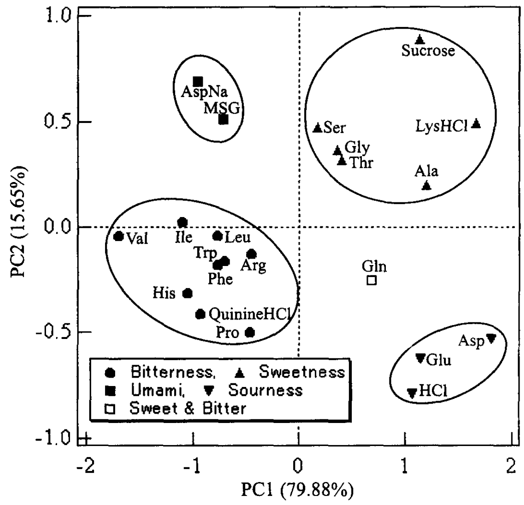


Fig.8 Scatter diagram of the **PCA** for amino acids and four chemical substances.

Sweet substances and bitter substances were located at positive and negative regions along the PC1 axis, respectively. Moreover, umami substances and glutamine which produces sweet and bitter were located between them. However, sour substances were found separately negative regions on the PC2 axis. Glutamine (Gln) elicits both sweet and bitter tastes, but sweet taste is stronger. The PCA for Gln are located between the sweet and bitter substances, although the potential profile pattern of the electrode impedance for Gln was similar to the response patterns of sweet taste substances. As noted above, the taste qualities of the amino acids were classified more clearly into four groups according to that of basic taste substances.

4. Discussion

Amino acids are used in processed foods because they enhance the nutritive value of many foods and also modify the natural taste characteristics of many foodstuffs, as is well known with MSG, which is a substance that shows the independent fifth taste, umami. The side chains of amino acids are very important. For example, the taste of an amino acid changes only if one group, R, is changed (**Fig.1**).

The most common conventional electrochemical methods involve oxidation-reduction processes. In this study, however, the change in the interaction between an electrode surface and chemical substances was investigated using the surface polarization of the electrode in aqueous solution where no redox reaction occurs. The tastes of amino acids and five basic chemical substances were studied using a method to detect the change in the interaction between an electrode surface and taste substances in aqueous solution. Electrochemical impedance was measured at each electrode surface potential to determine the condition of the surface. Therefore, we obtained different potential profiles formed according to the various inherent characteristics of chemical substances. Moreover, the change in the interaction between an electrode surface and chemical substances can be expected to yield information about taste, because the taste of chemicals depends mainly on the polarity of chemicals. The electrode impedance showed different patterns of potential profiles for amino acids with different taste qualities, while it showed similar patterns for amino acids with similar taste.

The potential profiles for basic taste substances producing different taste qualities were much different, and hence each taste could be easily discriminated (**Fig.4**). It implied that the taste of chemical substances could be qualitatively measured with the present method and be explained from the interaction based on the electrode polarity. In this way, the different electrode potential profiles were due to the changes in the surface potential, which involved ionic concentration changes according to dissociation and adsorption of taste substances on the electrode surface. The surface-polarity controlled sensor could easily distinguish not only the taste quality of the five basic taste substances but also amino acids. This surface-polarity controlled sensor could distinguish chemical substances taste itself. The taste quality could be reproduced by considering the electrode potential profiles of the surface-polarity controlled sensor.

The synthetic potential profiles of amino acids obtained by the curve fitting analysis were clearly discriminated for different taste substances such as sweet, bitter, sour and umami-tasting amino acids (**Fig.7**). In contrast, the taste sensor gave similar potential profiles for substances of the similar taste quality. It should be noted that taste sensation is a result of interactions between an electrode surface and taste substances, i.e., taste is not specific to or characteristic of each molecule. The response patterns of the sensor are not the amount of specific molecules to exhibit taste but the taste quality and intensity, because different potential profiles were obtained for different taste groups such as sweetness, bitterness, sourness and umami-taste.

On the other hand this sensor could be used to detect neutral substances which were difficult to discriminate with electrochemical method. The surface-polarity controlled sensor could also be applied to measurements of water pollution. It was possible to detect odor molecules or environmental pollution substances dissolving in water with high sensitivity.$^{8)}$ These results suggest that the present sensor can be utilized for detectors of multi purpose chemical sensor and has an ability of wide applicable sensor system.

5. Conclusion

The surface-polarity controlled sensor and measuring methods could respond to the taste itself. It was confirmed that surface-polarity controlled sensor can provide useful transducers for the development of taste sensors which can be used for qualitative analysis of taste. As a result of elimination of the basic peak around 0.1 V using a curve fitting analysis in the potential profiles of amino acids, the taste quality of amino acids could be classified into four groups according to their taste quality and compared with that of basic taste substances. The taste quality of chemical substances can be reproduced by the surface-polarity controlled sensor.

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