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Temperature Dependence of Bitter Taste and Output Characteristics of Taste Sensor

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The purpose of this study is to reproduce the exact taste that people feel, without eliminating the temperature dependence of a multichannel taste sensor. Four taste substances, NaCl (salty), HCl (sour), quinine-HCl (bitter) and monosodium glutamate (*umami*) were evaluated in terms of temperature dependence by humans. In the case of quinine-HCl, the strength of bitterness became weak at higher temperature. On the other hand, the four taste substances were measured in terms of temperature dependence using a multichannel taste sensor. The experiment on temperature dependence was carried out to improve the measurement device such that the electrode is not affected by temperature. Results showed that the response potential of quinine-HCl decreased with increasing temperature. It is suggested that an increase in temperature causes the weakening of hydrophobic bonds, and the adsorption of quinine-HCl to the membrane becomes weak. The results confirmed the temperature dependence of quinine-HCl and matched the taste evaluation results.

1. Introduction

Humans have five senses: sight, hearing, touch, smell, and taste. These senses are very important determinants of the delicacy of food.[(1)] The evaluation of taste using these senses is a method of judging deliciousness. However, it is difficult to judge deliciousness precisely even if the taster is excellent because there are differences in the state of health and individual preferences among tasters.

On the other hand, physical sensors reproducing the sense of sight, hearing and touch have already been utilized instead of the five senses. Odor and taste sensors reproduce the sense of smell and taste, respectively, which follow a detection mechanism

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for chemical substances. The taste sensor that we have developed is composed of a multichannel electrode imitating a taste detection mechanism.[2–6]

The sensor uses several lipid membranes as transducers of taste substances and the change in the electric potential pattern is used as basis for differentiating the taste of foods. This sensor has already been used in the quantification on various foodstuffs and beverages such as mineral water, beer, and coffee.[3,7,8] However, generally, measurements using a taste sensor are mainly carried out at room temperature. There is a suitable temperature for food and you may have experienced a change in the taste with temperature.[9,10]

A sensor must reproduce human senses; therefore, a multichanel taste sensor needs to reproduce the temperature dependence of taste in the future. In general, any sensing element has temperature dependence, and it is necessary to remove the temperature dependence of a sensor.

It has been reported that humans experience a change in the taste with temperature.[11–13] These reports cannot be compared because the experiment methods or results vary. Thus, we tried the sensory evaluation test for the four basic tastes (salty, sour, bitter and *umami*) by humans, and investigated the basic tastes with temperature dependence. The bitter taste showed a clear temperature-dependent change among the four basic tastes. Then, we attempted to compare the temperature dependence of the human taste sensory system with that of the sensor that we developed and to match the response characteristics of the sensor to those of the human taste sensory system for bitter taste.

2. Material and Methods

2.1 *Measurement system*

A change in taste cannot be measured using a taste sensor whose sensitivity depends on the temperature change of the internal solution. Before measuring a bitter substance using the measurement system shown in Fig. 1, the temperature change of the internal solution, with the probe filled with saturated KCl solution, was measured. We prepared a probe that has an internal solution capacity much larger than before to prevent the rise in temperature. The measurement system consisted of two electrodes, one is a lipid/polymer membrane electrode made of a thermocouple or Ag/AgCl electrode and another is a reference electrode that can detect the membrane lipid/polymer electric potential.

A lipid/polymer membrane was dissolved in 50 mM KCl prior to the measurement. The standard solution was 50 mM KCl. Samples were 1 mM KCl and 1 mM quinine-HCl, containing 1 mM KCl. Then, a lipid/polymer membrane was immersed at a depth of 30 mm from the surface; 1 mM KCl or sample and 50 mM KCl were also immersed in the water bath. The temperature was increased to 20 and to 60°C, the measurement was carried out for five min using 1 mM KCl or sample, and the change was analyzed.[4]

Table 1 shows the eight types of lipid/polymer membranes that were prepared for this measurement. Each lipid was mixed in a test tube with polyvinyl chloride (PVC) and a plasticizer (dioctyl phenylphosphonate, DOPP), which was then dissolved in tetrahydrofuran. Subsequently, the mixture was dried on a glass plate, which was placed

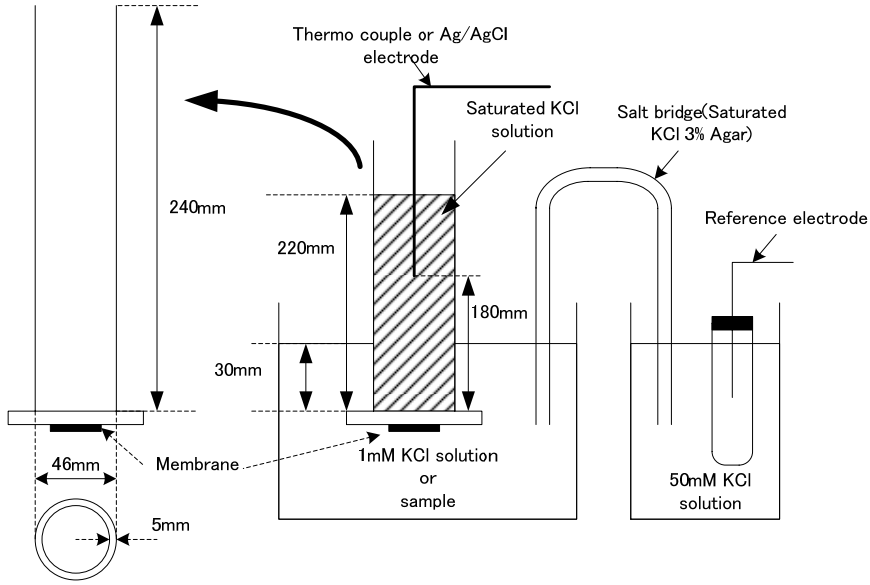

Fig. 1. Measurement system. The sensor probe consists of the probe main part, lipid/polymer membranes, Ag/AgCl electrode, internal solutions (saturated KCl and saturated AgCl) and an electrode terminal. The reference electrode consists of the probe main part, lipid/polymer membranes, Ag/AgCl electrode, internal solutions (saturated KCl and saturated AgCl), an electrode terminal, and saturated KCl 3% agar.

Table 1
Lipid membranes used in this study.

Electric charge	Channel	Lipid membrane (abbreviation)
+	3:7	DOP:TOMA = 3:7
	TOMA	Trioctyl methyl ammonium
0	5:5	DOP:TOMA = 5:5
+	OAm	Oleyl amine
−	DOP	Dioctyl phospate
	9:1	DOP:TOMA = 9:1
	DA	Decyl alcohol
	OA	Oleic acid

on a hot plate controlled at approximately 30°C. The prepared lipid/polymer membrane was a transparent, colorless soft film of about 200 μm thickness.

Decyl alcohol (DA), a lipid/polymer membrane, was selected for determining the

change in the absolute potential with changes in temperature because this membrane shows a large response to quinine-HCl.[7]

2.2 *Temperature dependence*

Figure 2 shows the measurement system for evaluating temperature dependence. This measurement system consists of a working electrode and a reference electrode. Each working electrode was made of a Ag wire, whose surface was plated with Ag/AgCl, with an internal solution filled with saturated KCl solution, fixed with eight types of lipid/polymer membranes on the lower part of the outer side.

On the basis of the results on the changes in temperature detected using the system shown in Fig. 1, that is, the internal solution of the electrode was not affected by temperature, we improved the measurement system. In the experiment on temperature dependence, we used a salt bridge to eliminate the effect of the temperature change on the reference electrode itself. The electric potential of a sample was measured at 25°C and then at 60°C, and recorded in a computer as the potential difference. Generally, this electrode is maintained at 25°C, and we experimented by limiting the time of soaking in the sample solution to five seconds. The samples were measured at 25°C and 60°C. Quinine hydrochloride, which is a typical substance with a bitter taste, was used as the sample.

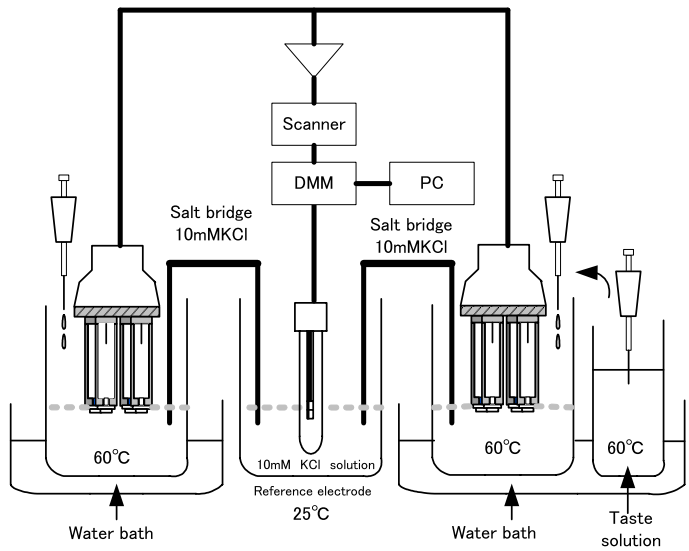

Fig. 2. Measurement system. Beakers are immersed in the water bath. The samples were maintained at a constant temperature.

2.3 *Sensory evaluation test*

Human evaluation of the four basic tastes was carried out by ten to fifteen panel members and the results are shown in Fig. 3. We used the following procedures in this system. The concentration of a sample was within a range in which one senses the taste at a low concentration. The panel members tasted about 30 ml of sample at different temperatures. The test was carried out for every taste substance. We then estimated the bitter taste in a scale of 3: a strong bitter taste was scored 3, a moderately bitter taste 2, and a weakly bitter taste 1. We calculated the average of each sample from the obtained data.

3. Results and Discussion

3.1 *Change in temperature of internal solution and temperature dependence*

Because it was important for the internal solution of each electrode of the sensor to detect a difference in temperature, we prepared a system, as shown in Fig. 1. As a result, it detected about 0.5°C change in 30 s and 1°C change in 60 s. When a temperature

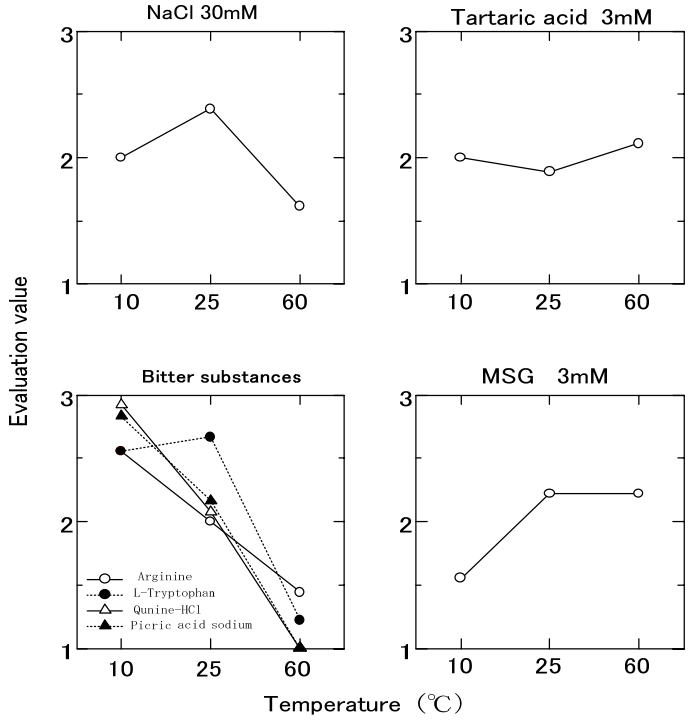

Fig. 3. Sensory evaluation by humans. Results are in agreement with the tendency of the sensor responses.

change was of this level, we considered that it did not have a large effect on the response potential of lipid/polymer membranes.

Figure 4 shows the difference in response electric potential for quinine-HCl at 25°C and at 60°C. Except for several lipid membranes, when at a higher concentration, the response potential increases. In addition, at a much higher concentration, the response potential further increases, which is a response pattern for a typical bitter taste. This observation indicates that the higher the concentration, the more bitter the taste is felt.

On the other hand, according to theory and the Nernst equation, it is expected that the electric potential as the response increases with temperature. However, the electric

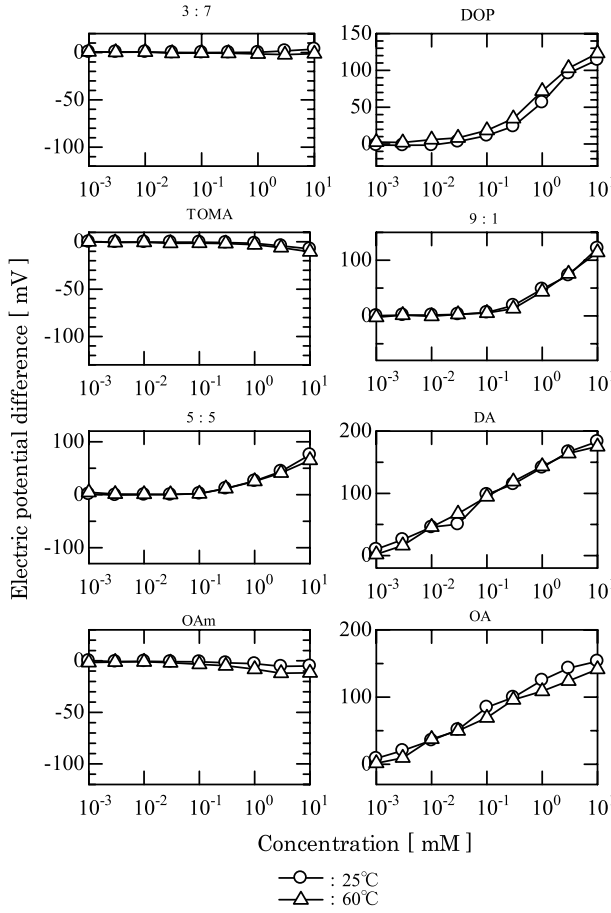

Fig. 4. Response potential difference at 25°C and 60°C for quinine-HCl. As the quinine-HCl concentration is increased, the electric potential of the negatively charged membranes increased. There is little difference between electric potentials at 25°C and 60°C in terms of the shape of the concentration dependence. The response at higher temperature decreased in most channels.

potential of only a specific membrane decreased. Furthermore, we investigated the electric potential changes of DA using the system shown in Fig. 1. The results are shown in Fig. 5.

There was almost no change in the absolute potential of 1 mM KCl, which was used as the standard solution. However, the absolute potential of 1 mM quinine-HCl decreased with increasing temperature.

It is generally considered that the response mechanism of KCl is an electric response, and that the response mechanism of quinine-HCl is both an electric response and a hydrophobic response. Moreover, it is generally known that a hydrophobic bond becomes strong with increasing temperature. In addition, the hydrophobic bond becomes strong between the hydrophobic parts of quinine-HCl with increasing temperature. Thus, we suggested that quinine-HCl did not absorb onto the membranes because hydrophobic interactions become weak between the hydrophobic part of the membrane and the hydrophobic part of the quinine-HCl. Therefore, the electric potential of quinine-HCl decreased owing to the weakening of hydrophobic bonds of different tastes.

Next, Fig. 6 shows the comparison of four typical substances, NaCl (salty), HCl (sour), quinine-HCl (bitter), and monosodium glutamate (MSG (*umami*)).

There were few differences in the response potential pattern at 25°C and 60°C. When the temperature was high, the responses to NaCl and quinine-HCl became strong. However, only the response of the negatively charged membrane became weak with an increase in temperature of quinine-HCl.

3.2 *Comparison with taste sensory evaluation*

Next, we compared the temperature dependence of the human taste sensory system with that of the sensor we developed and considered to match the responses of our sensor to those of the human taste sensory system. The results are shown in Fig. 3. NaCl, tartaric acid, and MSG did not show a clear pattern of response. The bitter taste score decreased at a high temperature and increased at a low temperature.

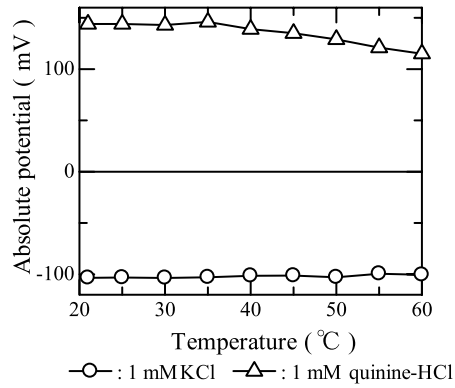

Fig. 5. Changes in response potential with changes in temperature.

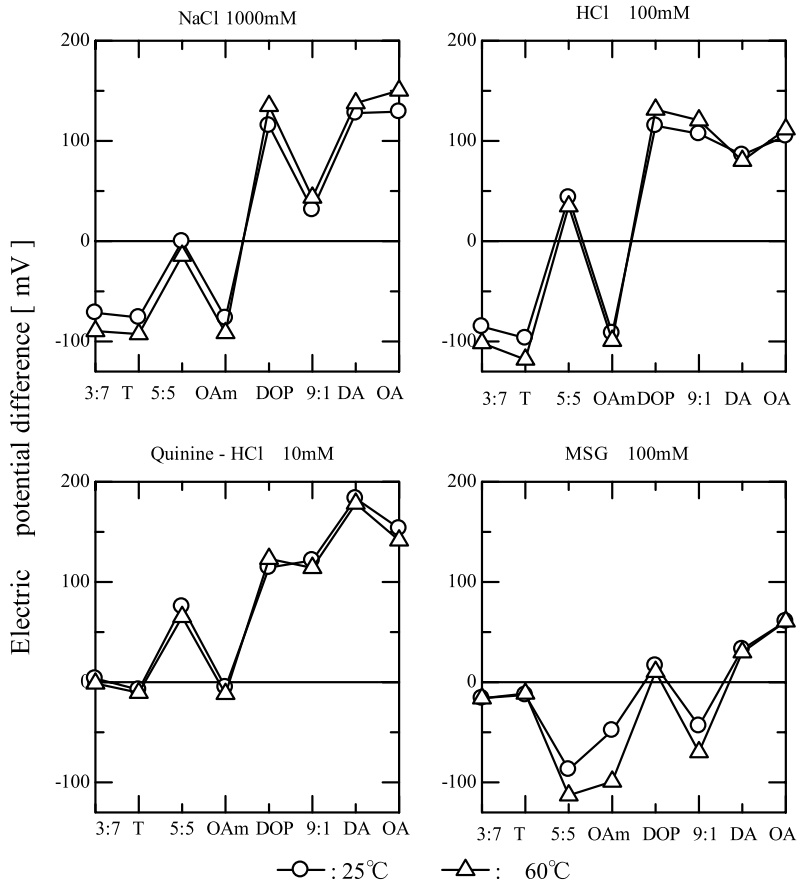

Fig. 6. Response patterns for four basic substances.

In the present case, the taste of humans changes with temperature, and the general sensor also shows the same tendency. We desire that a multichannnel taste sensor's measurement is temperature-dependent. Therefore, the sensor has to neglect the effect of temperature.

In this study, we investigated the changes in taste with changes in temperature using a multichannel taste sensor. A taste evaluation by humans carried out simultaneously showed that the solutions containing bitter substances such as quinine-HCl had low scores for bitterness at higher temperature. This observation agrees with the output characteristics of the multichanel taste sensor.

Hence, the temperature dependence of bitter taste analyzed using the multichannel taste sensor and the matching of the sensor output characteristics to the results obtained by human evaluation have been confirmed. We found that the multichannel taste sensor can reproduce the temperature dependence of bitter taste by comparing with the human taste evaluation results.

It is expected that measuring changes in taste with changes in temperature of foodstuffs using a multichannel taste sensor is useful for product development in the food industry.

4. Conclusions

Temperature is one of the important factors that determines the delicacy of food. Previous reports on the temperature dependence of basic tastes, however, differed depending on the researcher. To investigate the temperature dependence of basic taste, evaluations of the four basic tastes by human and a multichannel taste sensor were carried out in this study. First, the sensory test of quinine-hydrochloride by human became difficult at high temperature, while the other types of taste did not show marked temperature dependence. Second, the measurement of the temperature dependence of quinine-HCl using the taste sensor showed that the response decreased with increasing temperature in the same way. The results suggested the reproducibility of the temperature dependence of taste using a multichannel taste sensor.

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