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Taste Sensor

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Introduction

We have first developed a taste-sensing system whose transducer is composed of lipid/polymer membranes (Toko, 1998, 2000). The output of this system is not the amount of specific taste substances but the taste quality and intensity, because different output electrical patterns are obtained for chemical substances producing different taste qualities such as sourness and bitterness. On the other hand, similar patterns are obtained for chemical substances producing the same taste, such as monosodium glutamate (MSG), disodium inosinate (IMP) and disodium guanylate (GMP), which have an umami taste and NaCl, KCl and KBr for saltiness.

The development of this sensor is based on a concept very different from that of conventional chemical sensors, which selectively detect specific chemical substances such as glucose or urea. However, taste cannot be measured even if all the chemical substances contained in foodstuffs are measured. Humans express the taste itself; the relationship between chemical substances and taste is not clear. It is also not practical to arrange as many chemical sensors as chemical substances, which may number >1000 in one kind of foodstuff. Moreover, there exist interactions between taste substances, such as suppression effects. Sweet substances or bitter-masking substances suppress the taste intensity of bitter substances.

Discrimination of each chemical substance is not important here, but recognition of the taste itself and its quantitative expression should be made. The taste sensor using lipid/polymer membranes has a concept of global selectivity which implies the ability to classify large numbers of chemical substances into several groups according to their taste.

Taste sensor

Different kinds of lipids were used for preparing the membranes; lipids used were, for example, oleic acid (OA), oleyl amine (OAm), decyl alcohol (DA), etc. Depending upon the item to be measured, we prepared different lipid materials. For example, mixed hybrid membranes composed of dioctyl hydrogen phosphate (DOP) and methyltrioctylammonium chloride (TOMA) were also used. The lipid/polymer membrane was a transparent, soft film with a thickness of ~200 μm.

Each lipid/polymer membrane was fitted on part of a plastic tube which had a hole, such that the inner part of the cylinder is isolated from the outside. The end of the cylinder was sealed with a stopper that held an Ag/AgCl wire. The tube was filled with 3 M KCl solution. Eight detecting electrodes thus prepared were separated to two groups and connected to two electrode holders, which were controlled mechanically by a robot arm.

Pharmaceutical application

It is important for pharmaceutical sciences to express the extent of bitterness. To date, however, the main method of measurement has been sensory evaluation made by humans. Tasting bitterness stresses human inspection, while conventional chemical analyses are subsidiary methods. Therefore, taste-sensing devices to detect the bitterness have been desired for a long period. There is a suppression effect for bitterness, where bitterness is suppressed by coexistence of sweet substances such as sucrose. To quantify the bitterness, it is necessary to measure the taste by taking account of the suppression effect. We tried to detect this effect using the taste sensor.

First, principal component analysis (PCA) was applied to response patterns for quinine from 0.1 to 10 mM. The contribution rate of the original data to PC1 was 95.4 %. This means that PC1 characterizes the patterns and we can discuss these data using only PC1. PC1 increased in proportion to the quinine concentration on a logarithmic scale. This relation agrees with the well-known Weber–Fechner law of human sensory evaluation, which states that the sensation is proportional to the logarithm of stimulus intensity. Therefore, PC1 can be considered to express the strength of bitterness. The bitter strength of L-tryptophan was accurately estimated using this scale obtained from the taste sensor.

The bitter strength was estimated from the response potentials for samples which contain 1 mM quinine and sucrose with five different concentrations. The taste sensor exhibited decreasing strength of bitterness with increasing sucrose concentration. This result implies a satisfactory detection of the suppression of bitterness induced by sucrose (Takagi *et al.*, 1998).

The same measurement and procedure as above was made on a drug substance. As a result, the decrease of the bitter strength of a drug substance with increasing sucrose concentration was quantified.

This suppression effect was studied using the taste sensor and a commercial bitter-masking substance (BMI-60) composed of phospholipids; its ingredients are 15–20% PA, 5% phosphatidylcholine, 40% phosphatidylinositol and 10–15% phosphatidylethanolamine.

The change in bitter intensity of quinine solutions of two different concentrations of 0.1 and 1 mM was studied as a function of the concentration of bitter-masking substance. The reduction of bitter intensity occurred at 0.1 and 1 mM quinine, whereas the reduction rate was much larger at 0.1 mM than at 1 mM. The bitter intensity of 0.1 mM quinine was effectively decreased to the level of no taste by addition of 1% BMI-60. The agreement between the result of the taste sensor and human sensory evaluations was fairly good (Takagi *et al.*, 2001).

Figure 1 shows observation of the surface of lipid/polymer membrane made of decyl alcohol (DA) using atomic force microscopy (AFM) (Shimakawa *et al.*, 2004). The surface was greatly changed by application of quinine. However, it was returned to the original state by addition of the bitter-masking substance. This means that this substance inhibited the binding of quinine molecules to the lipid membrane and this is the reason why bitterness was weakened.

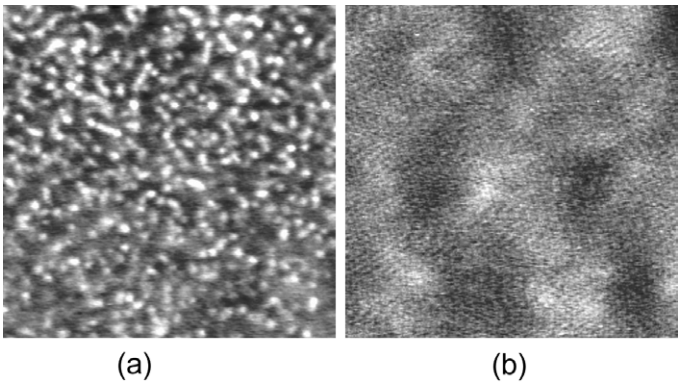

Figure 1 Surface morphologies of decyl alcohol (DA) membrane with **(a)** application of quinine and **(b)** with addition of BMI-60 (Shimakawa *et al.*, 2004). The full range is 500 × 500 nm and the height is 2 nm in (a) and (b).

Improvement of sensitivity for sweetness

We tried to improve sensitivity for sweet tasting substances, because the potentiometric measurement used in the taste sensor was inadequate to obtain large sensor outputs for these substances due to its nonelectrolyte property. The outputs for sweetness have been relatively low so far, one-fifth to one-tenth, compared with other basic taste substances. According to a chemoreception theory (Shallenberger and Acree, 1967), there are common molecular structures between sweet tasting substances and the receptors. Interaction between hydrogen donor and receptor groups is required for chemical substances to be perceived as sweet. In this study we focused on the property that the molecule would receive protons from receptors.

The length of the hydrophobic group seems to play a key role in the electrical response for sucrose. The electrical potential of membrane surface should be neutral in order to gain higher sensitivity for sweetness to avoid interfering factors such as coexistent electrolytes. For this purpose we selected lipids with hydrophobic properties and then varied the charge density by increasing positively charged lipids. As a result, the sensitivity for sucrose was optimized based on the surface electric potential of membrane. The sensor output for sucrose showed almost five to ten times higher sensitivity than that of conventional lipid/polymer membranes (Habara *et al.*, 2004).

In this study we developed a sweetness-sensitive lipid/polymer membrane. However, the response mechanism is still under investigation. If preconditioning procedures cause some surface modifications on the membrane, it would be useful to examine a surface observation using an technique such as AFM. Another issue is how the change of membrane electrical potential is caused by nonelectrolytes such as sucrose. A reasonable answer would be the change of dissociation constant on the membrane surface because of some interaction.

We are now planning to construct a taste/smell recognition microchip with the aid of semiconductor technology. A multi-modal communication to include the transmission of taste and smell will be realized, if this kind of chip that fuses the taste and smell sensors is developed. It opens a new paradigm in the IT world.

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