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Quantification of Taste of Coffee Using Sensor with Global Selectivity

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The tastes of different kinds of coffee were measured using a taste sensor. It was found that the lipid membranes of the sensor can be used safely at temperatures as high as 60°C for half a year. Coffees processed by a roasting-brewing procedure were easily discriminated; very high correlations were found between the response electric potentials of the taste sensor and the results of sensory tests by humans for acidity and bitterness, which are the characteristic tastes of coffee. The results imply that the taste of coffee can be quantified by this objective measure. The taste of commercial liquid canned coffees was also quantified, and a two-dimensional taste map was obtained. These results are due to the global selectivity of the taste sensor, which responds simultaneously to tastes of various substances in foodstuffs and classifies them into characteristic groups of taste qualities.

1. Introduction

Presently, the production of coffee depends on the sensory evaluation of humans. However, the human sensory system varies depending on daily physical and mental conditions. To enable continuous automatic production of coffee with reliable quality, a sensor which provides an objective measure of the taste, together with the sensory

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evaluation by humans, is highly desired.

Taste is a combination of five basic taste qualities. The first is sourness (or "acidity" in the field of coffee production) produced by hydrogen ions. The second is saltiness produced by NaCl and KCl. The third is bitterness produced by quinine and caffeine. The fourth is sweetness produced by sucrose and glucose, among others. The last is umami, which implies "deliciousness" in Japanese and is produced by monosodium glutamate (MSG), disodium inosinate (IMP) and disodium guanylate (GMP).[1–4] Taste substances are received by the biological membrane of gustatory cells in taste buds on the tongue.

Recently, we have developed a multichannel taste sensor whose transducer consists of lipid membranes.[5–13] This sensor can detect tastes in a manner similar to human gustatory sensation. Different response electric potentials were obtained for different taste groups such as sourness and saltiness, whereas similar response electric potential patterns were obtained for substances in the same group such as MSG, IMP and GMP, which produce an umami taste, and NaCl, KCl and KBr, which produce saltiness.

The taste sensor was developed based on a concept that is very different from that of conventional chemical sensors which selectively detect specific chemical substances; i.e., the taste sensor functions on a new concept of global selectivity. Humans do not distinguish chemical substances individually, but express the taste of various chemical substances as a whole. It is also impractical to fabricate specific sensors for specific chemical substances contained in foodstuff. Moreover, humans experience interactions between taste substances, such as a suppression effect or a synergistic effect.[1–4] A taste sensor must be able to measure these effects.

In the present paper, a taste sensor was used to quantify the taste of 11 kinds of coffee from different origins. Quantification of the taste of coffee such as acidity and bitterness was achieved using the taste sensor.

2. Materials and Methods

The taste of 11 kinds of coffee from different origins was quantified: Salvador (CS), Brazil (Santos No. 2), Guatemala (SHB), Jamaica (Blue Mountain No. 2), Hawaii Kona (Extra Fancy), Kenya (AA), Tanzania (AA), Colombia (Excelso), Indonesia Mandheling (Grade1), Indonesia WIB 1 and Indonesia AP 1. After coffee grains were roasted, they were crushed roughly. Then, 8 g of the resulting powder of each kind of coffee was put into a tumbler, to which 150 ml hot water of about 95°C was added. Coffee produced by the above roasting-brewing procedure was stirred three times using a spoon, and then allowed to cool down to 60°C.

Measurements of the taste of the coffee were made using a commercial taste-sensing system (SA401) of Anritsu Corp. The detecting sensor part consists of seven electrodes made of lipid membranes (i.e., channels), and is controlled mechanically by a robot arm, as illustrated in Fig. 1. The membranes were No. SB00 for channel 1 (control), No. SB01AAC1 for ch. 2 and 3, No. SB01AAF1 for ch. 4 and 5, and No. SB01AAJ1 for ch. 6 and 7, which were immersed in Salvador coffee (standard), for at least one month. The membranes of ch. 2 and 3 are negatively charged, those of ch. 4 and 5 positively charged, and those of ch. 6

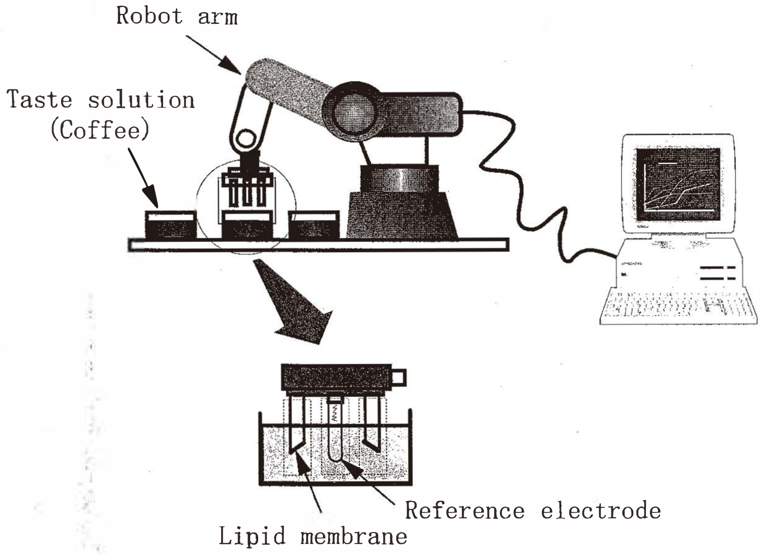


Fig. 1. Taste-sensing system (SA401) developed by Anritsu Corp.

and 7 weakly negatively charged. The response electric potentials were measured relative to the zero response potential to Salvador coffee. The measurements of 10 kinds of coffee from different origins were made two times by the rotation procedure, which involved two rounds of measurement. The average values of two measurements were adopted as the response electric potential pattern.

The lipid membranes used were made from polyvinyl chloride (PVC), plasticizer and lipids in the same manner as before.[5–13] The lipid membrane was a transparent, colorless soft film of about 200 μm thickness. Lipid membranes were fitted to seven hollow-cylinder electrodes, which were connected to a seven-channel scanner through high-input impedance amplifiers. The selected electric signals from the sensor were digitized by a digital voltmeter and fed to a computer. Then, the voltage difference between the lipid membrane electrodes and a reference electrode was measured.

The sensory test by humans was also performed by 9 members of a panel with coffee prepared by the above roasting-brewing procedure. The terms "acidity" and "bitterness" of coffee were evaluated in 5 levels, where Salvador coffee was set at level 3 as the intermediate (basic) level of the tastes.

Temperature of the coffee to be measured was about 60°C. As a preliminary experiment, therefore, the heat durability of the lipid membranes was studied first. The lipids used are listed in Table 1. Measurements were performed using NaCl solution with 9 different concentrations ranging from 0.1 mM to 1000 mM at 20°C, 40°C and 60°C.

Table 1
Lipids used for the membranes. Channels 2–4 are the hybrid membranes of DOP and TOMA mixed according to the molar ratio shown. Using this set of membranes, the heat durability was studied, and the results are shown in Fig. 2. Measurements of coffee taste were made using commerricial electrodes with lipid membranes.

Channel	Lipid
1	Dioctyl phosphate (DOP)
2	DOP : TOMA = 9 : 1
3	DOP : TOMA = 5 : 5
4	DOP : TOMA = 3 : 7
5	Trioctyl methyl ammonium chloride (TOMA)
6	Oleic acid
7	Oleyl amine

3. Results

Figure 2 shows the time course of response electric potential of the seven electrodes to 0.3 mM NaCl at 60°C as an example. It can be seen that the response electric potential is fairly stable up to 170 min. The response electric potential was also fairly stable even up to 26 h at 60°C to the 9 different NaCl concentrations (data not shown). This result implies that lipid membranes can be used at high temperatures.

Figure 3 shows the response electric potential to Brazil (Santos No. 2) with standard deviations obtained for three measurements. It can be seen that the standard deviations are as small as 0.1 mV.

Figure 4 shows the response electric potentials to 10 kinds of coffee from different origins, Brazil (Santos No. 2), Guatemala (SHB), Jamaica (Blue Mountain No. 2), Hawaii Kona (Extra Fancy), Kenya (AA), Tanzania (AA), Colombia (Excelso), Indonesia Mandheling (Grade1), Indonesia WIB 1 and Indonesia AP 1, relative to the response electric potential to Salvador (CS), which was used here as the standard coffee (i.e., zero level of response electric potential pattern). We can see that Kenya (AA) shows the highest response electric potential, while Indonesia AP 1 shows the lowest response electric potential. Since the standard deviations of the measurement system were 0.1 mV in Fig. 3, the 10 kinds of coffee could be easily discriminated.

Figure 5 shows the result of principal component analysis applied to the response electric potential patterns in Fig. 4. The 11 kinds of coffee are found to be distributed on the two-dimensional plane of the first (PC1) and second (PC2) principal components. The contribution rates of original data to PC1 and PC2 are 82.2% and 13.8%, respectively; hence we can satisfactorily discuss the taste of coffee on the two-dimensional plane. In other words, the taste of coffee can be quantified by at least two independent expressions. Factor loadings to PC1 were positive for all channels, and hence seven channels can be considered to contribute equally to PC1.

As is well known, the taste of coffee is characterized by the terms acidity and bitterness.

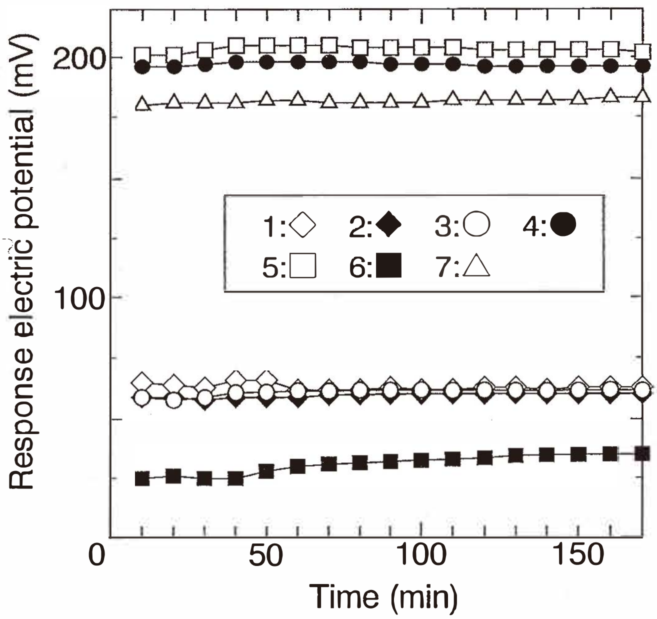


Fig. 2. Response of lipid membranes to 0.3 mM NaCl at 60°C.

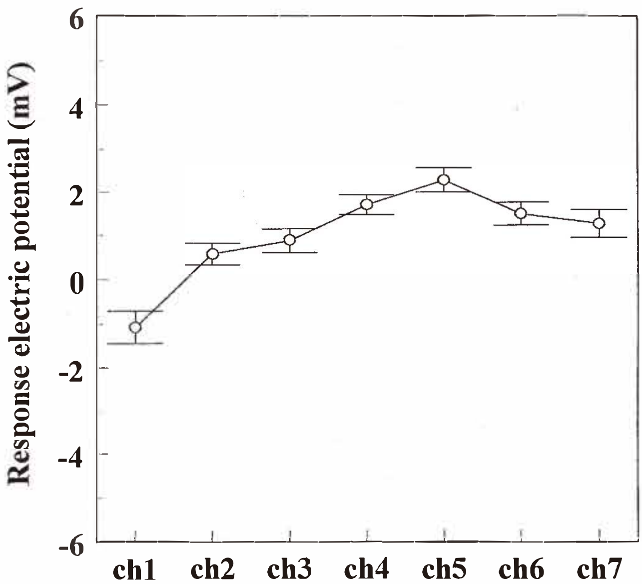


Fig. 3. Response pattern for Brazil (Santos No.2) with standard deviations, measured relative to the zero response electric potential to Salvador.

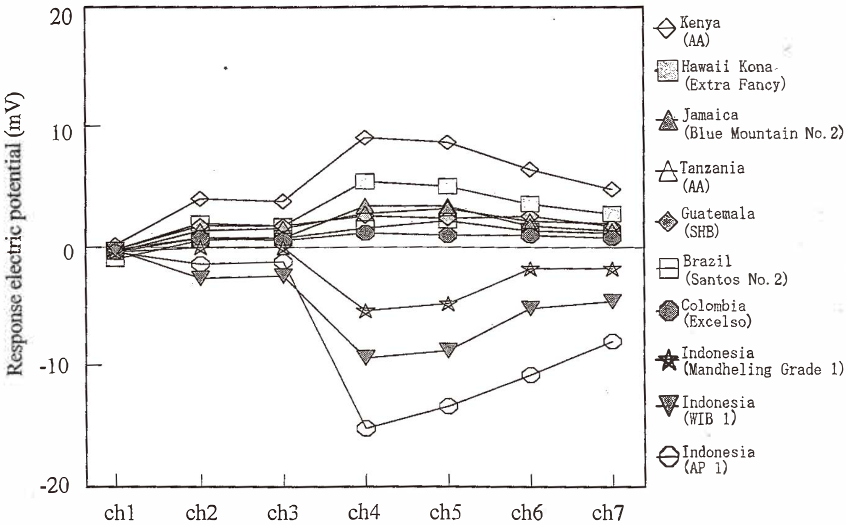


Fig. 4. Response patterns for 10 kinds of coffee from different origins.

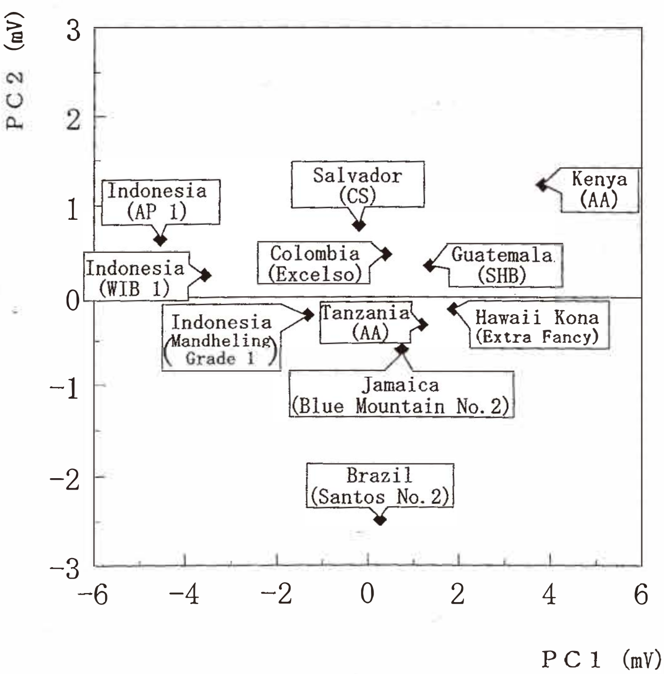
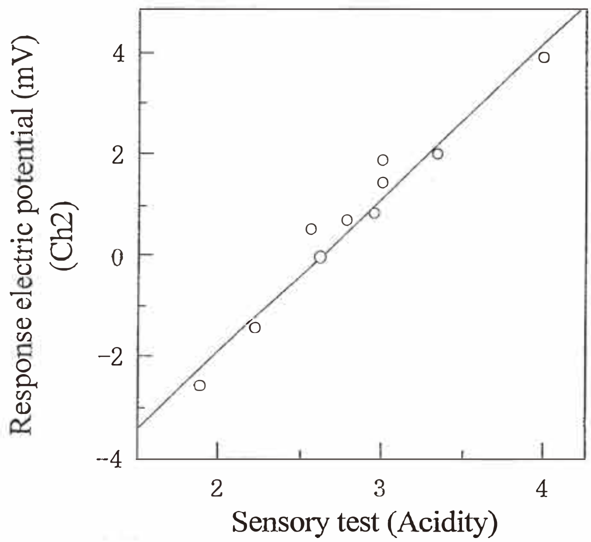


Fig. 5. Principal component analysis applied to the response patterns for 11 kinds of coffee from different origins.

Acidity is used to express a basic, sharp yet pleasing taste produced by organic acids contained in coffee.[14] Figure 6 shows the correlation between the response electric potential and the sensory test for acidity (a) and bitterness (b). The correlation coefficients

(a)



(b)

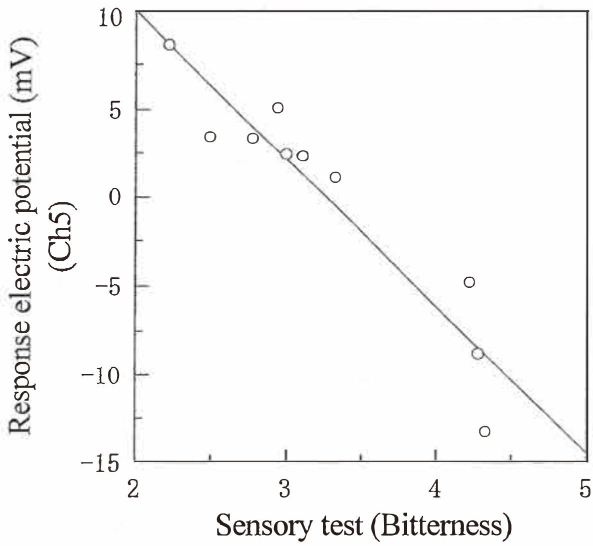


Fig. 6. Correlation between the sensor output and the sensory test by humans for acidity (a) and bitterness (b).

were 0.98 for acidity using channel 2 and 0.94 for bitterness using channel 5. These results imply that channels 2 (and 3) and 5 (and 4) can be utilized to quantify acidity and bitterness, respectively. For example, Kenya has strong acidity while Mandheling has strong bitterness, as is well known; this fact can be expressed using the quantified scale obtained from the sensor output.

Next, we investigate the applicability of the taste-sensing system to commercial liquid canned coffees. Figure 7(a) shows the response electric potentials to 12 brands of canned coffee, measured relative to the zero response electric potential to BLACK MUTOU, which is a sugarless canned coffee. We can see that the response electric potentials differ from each other and are much larger than in the case of brewed coffee in Fig. 4. Channels 2 and 3 responded strongly to coffee with a milky taste. We can discuss the taste of canned coffee based on these results.

Figure 7(b) is the result of principal component analysis applied to Fig. 7(a). From the comparison with human sensory tests, PC1 was found to reflect "milky taste" and PC2 "full-bodied taste." Factor loadings to PC1 were positive for ch. 1–3, 6 and 7, but negative for ch. 4 and 5. This difference between channels may originate in the difference of the electric characteristics between negatively charged lipid membranes (ch. 2, 3, 6, 7) and positively charged membranes (ch. 4, 5) for fat components of canned coffee.

4. Discussion

Taste of different kinds of coffee was quantified using a sensor. Very high correlations were found between the response electric potentials of the taste sensor and the results of sensory tests by humans for acidity and bitterness. If we regard the ordinate in Fig. 6, i.e., the response electric potential, as a measure of acidity (or bitterness), then the taste of coffee can be quantified by this objective measure. In addition, the sensitivity is as high as ± 0.1 mV, hence minute differences of taste of different brands (and also of the same brand with different production dates) of coffee can be accurately detected.

Acidity and bitterness cannot be deduced from chemical components contained in coffee. In fact, caffeine-free coffee tastes bitter, although caffeine is considered to be a main component that produces bitterness in coffee. It implies that the sensory expressions for taste qualities originate in a complex combination of many chemical components. In such cases, a sensor with high selectivity to a particular chemical substance is not useful. The taste sensor with lipid membranes can respond to many kinds of chemical substances at the same time; i.e., the sensor shows global selectivity to chemical substances. Based on this reason, acidity and bitterness of coffee can be quantified, as in the case of titrable acidity of Japanese sake which is expressed by pH, amino acid content and organic acid content.[6]

The taste sensor will be applicable to quality control of coffee and also to large-scale production. The human sensory system varies depending on subjective factors such as human condition. If we compare the results of the taste sensor with those of the sensory test, we will be able to assess taste objectively. Moreover, the mechanism of information processing of taste in the brain as well as the detection by taste cells will be clarified by developing a taste sensor which has output similar to that of the biological gustatory system.

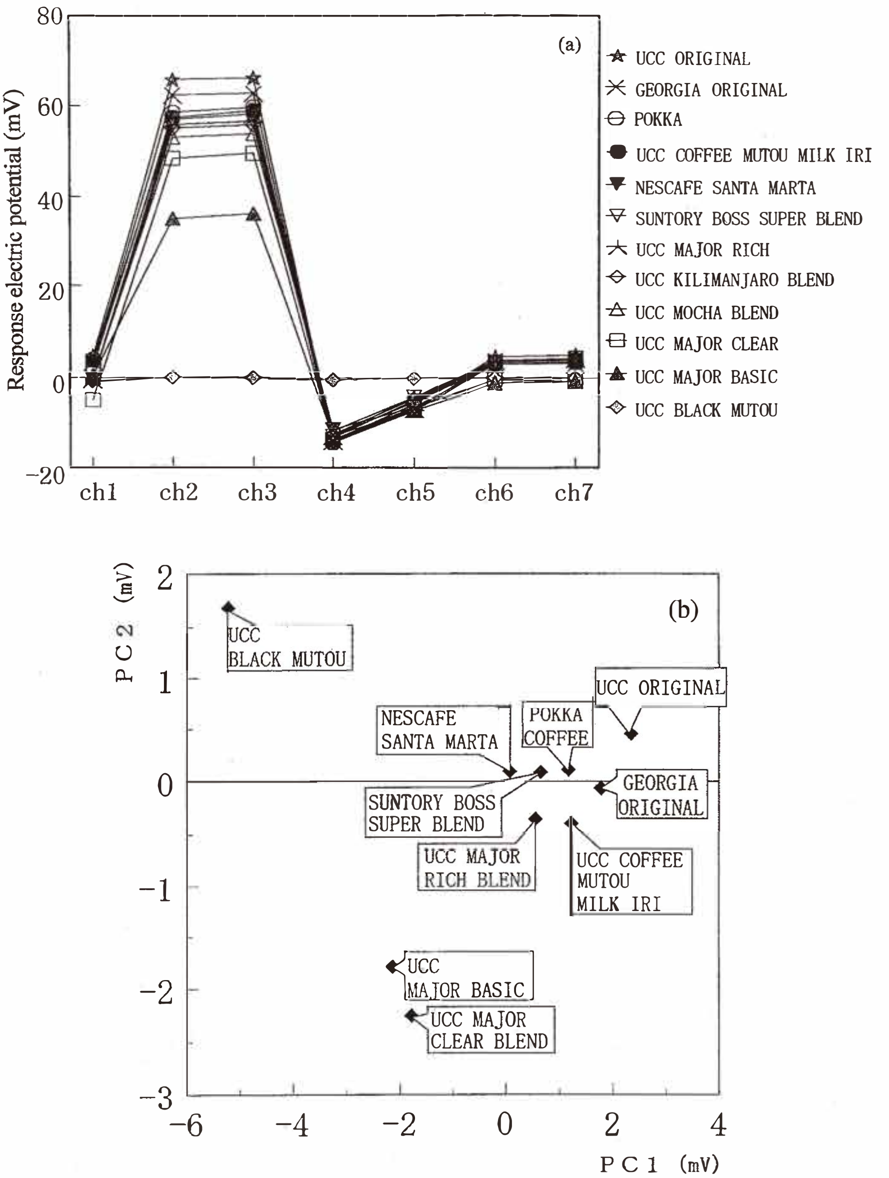


Fig. 7. Response patterns for 12 brands of canned coffee (a) and principal component analysis (b).

References

1 R. M. Pangborn: Food Res. **25** (1960) 245.
2 L. M. Bartoshuk: Physiol. Behav. **14** (1975) 643.
3 C. Pfaffmann: The sense of taste, Handbook of Physiology, Sec. 1 Neurophysiology, Vol. 1, ed. J. Field (American Physiological Society, Washington D.C., 1959) p.507.
4 Y. Kawamura and M. R. Kare (eds.): Umami: A Basic Taste, Marcel Dekker, Inc., New York, 1987.
5 S. Iiyama, M. Yahiro and K. Toko: Sensors and Materials **7** (1995) 191.
6 Y. Arikawa, K. Toko, H. Ikezaki, Y. Shinha, T. Ito, I. Oguri and S. Baba: Sensors and Materials **7** (1995) 261.
7 H. Ikezaki, K. Hayashi, M. Yamanaka, R. Tatsukawa, K. Toko and K. Yamafuji: Trans. IEICE Japan **J74-C-II** (1991) 434 [in Japanese].
8 T. Murata, K. Hayashi, K. Toko, H. Ikezaki, K. Sato, R. Toukubo and K. Yamafuji: Sensors and Materials **4** (1992) 81.
9 K. Toko, T. Murata, T. Matsuno, Y. Kikkawa and K. Yamafuji: Sensors and Materials **4** (1992) 145.
10 Y. Kikkawa, K. Toko and K. Yamafuji: Sensors and Materials **5** (1993) 83.
11 K. Toko, T. Matsuno, K. Yamafuji, K. Hayashi, H. Ikezaki, K. Sato, R. Toukubo and S. Kawarai: Biosens. Bioele. **9** (1994) 359.
12 Y. Kikkawa, K. Toko, T. Matsuno and K. Yamafuji: J. J. Appl. Phys. **33** (1994) 5731.
13 S. Iiyama, K. Toko, T. Matsuno and K. Yamafuji: Chem. Senses **19** (1994) 87.
14 International Coffee Organization (ed.): Consumer-Oriented Vocabulary for Brewed Coffee, Report No. 3 (1991) p.4.