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RESEARCH NOTE

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Prediction of the Freshness for Soybean Curd by the Electronic Nose in the Fluctuating Temperature Condition

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Abstract Freshness of stored soybean curd as sensitivity (R_{gas}/R_{air}) was evaluated at 48-50 hr intervals using electronic nose at regular sequential square-wave temperatures between 4 - 10°C. Obtained kinetic data from apparent first principal component score $(PC1)_{app}$ and storage time were used for prediction of freshness. Percentage difference between predicted and actual values of stored soybean curd was less than 8.9% under fluctuating temperature condition.

Keywords: soybean curd, electronic nose, fluctuating temperature

Introduction

Shelf life, often closely associated with freshness, is also increasingly important for products that are normally not associated with freshness, such as milk products, beverages, confectionary products, frozen products, and meat products. Food industry is also particularly interested in developing methods to improve the freshness characteristic and shelf life of ingredients that are used in foods.

The shelf life of soybean curd in refrigerator is generally 3~7 days, but may be further reduced through contamination with microorganisms or lipid oxidation. Therefore, if the quality of soybean curd could be checked prior to leaving the factory and controlled during distribution, better quality products without off-flavor would be available to the consumers; incubation and counting of microorganisms generally take more than 24 hr.

Kim *et al.* (1) reported that simultaneous oxygen consumption by microorganisms in filled water and tofu could be used to predict shelf life instead of counting the number of microorganisms. However, although the number of microorganisms can be estimated through this method, the off-flavor caused by lipid oxidation cannot be measured.

Classical microbial evaluation of perishable foods has limited value for predictive prognoses, because these foods are sold or eaten before the microbiological results become available. Therefore, in recent years, rather than measuring the total numbers of bacteria, techniques measuring the chemical changes produced by bacteria have been investigated (2).

Headspace analysis by GC or GC/MS can identify and quantify the composition of volatile compounds. However, although this method is precise and objective, it functions only on specific parts of smell and taste, and not always on parts considered most significant by the human senses. Moreover, skilled people are necessary for the interpretation of data, along with sample extraction and pretreatment time for GC analysis.

Usages of the electronic nose for the analysis of volatile compound have been studied on lipid oxidation of soybean oil (3), shelf life of soymilk (4), freshness of milk (5), and microencapsulated DHA (6). Saevels *et al.* evaluated the potential of the mass spectrometer-based electronic nose to monitor changes in apple fruit volatiles during storage (7).

Park *et al.* (8) showed that the shelf life of soybean curd could be predicted using the electronic nose. However, they obtained kinetic data from the soybean curd stored at constant temperature. In reality, foods rarely experience constant temperature. In the course of processing, distribution, and storage, foods are subjected to temperature fluctuations, which affect the rate of deterioration as well as the accumulated extent of deterioration (9). Therefore, the prediction of freshness should be considered under various environmental conditions.

Although principal component first score (PC1) has not been used for kinetic analysis, because it is not the actual concentration of a component, it is nevertheless correlated to temperature. Thus, because Arrhenius model showed that reaction rate is dependent upon temperature, PC1 could be applied to kinetic analysis.

The objective of this study was to evaluate the quality assessment of stored soybean curd under fluctuating temperature using an electronic nose. The obtained kinetic data from principal component analysis were also applied to predict the freshness of soybean curd.

Materials and Methods

Soybean curd samples Soybean curds were obtained from a local market in Seoul, and stored at 5, 15, 25, and 35°C for 12 days. Appoximately 6 g samples were used for the analysis by electronic nose. Soybean curd was repeatedly stored at 48-50 hr intervals at regular sequential square-wave temperatures between 4 - 10°C for 12 days under fluctuating temperature condition.

Analysis by the electronic nose The electronic nose system was constructed for dynamic headspace analysis of soybean curd (10). The analysis was carried out in triplicates for each sample. Six grams of soybean curd was

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placed in a 325-mL bottle. The equilibrium time for analysis was about 5 min. All measurements were conducted at 40°C. The headspace was purged from a sample vial using purified air at 10 mL/min.

Principal component analysis Responses of each sensor in the electronic nose were analyzed statistically using principal component analysis to evaluate the freshness of soybean curd. Multivariate statistical analysis program (MVSAP, version 4.0) software developed by Lee *et al.* (11) was used for principal component analysis.

Kinetics Rate constant was obtained from the relationship between PC1 and storage time at different temperatures (8).

$$(PC1)_i = k_i \times \theta_i + \text{intercept} \quad (1)$$

where $(PC1)_i$, k_i, and θ_i are principal component first score, rate constant, and storage time (hr) at i °C, respectively.

At a constant intercept, equation (1) would change to:

$$((PC1)_{app})_i = k_i \times \theta_i \quad (2)$$

The relationship between the obtained rate constant and storage temperature was plotted. Unknown rate constant at untested temperature was found from this relationship. Multiplying the rate constant and storage time as follows summed the accumulation of quality deterioration under fluctuating temperature condition:

$$\text{Sum of } ((PC1)_{app})_i = k_4 \times 48 \text{ hr} + k_{10} \times 50 + k_4 \times 48 + k_{10} \times 48 + k_4 \times 48 + k_{10} \times 48 \quad (3)$$

Results and Discussion

Analysis by the electronic nose The volatile components in soybean curds during storage were determined by the electronic nose at 48-hr intervals. The production of volatile compounds increased at high temperatures or for longer period, which could be due to food deterioration caused by microorganisms or chemical reactions such as lipid oxidation. Fortunately, the freshness of the stored samples at different temperatures could be easily separated based on the response of the electronic nose.

Kinetic analysis The obtained PC1 is correlated with the storage time depending upon the storage temperature. Good correlations were found at 5, 15, and 25°C as shown in a previous paper (8). Table 1 shows the relationship between PC1 and storage time.

At 5°C the modified relationship was described as follows:

$$((PC1)_{app})_i = PC1 - 0.52 = -0.0015 \times \text{storage time} \quad (4)$$

The rate constants at constant temperatures of 15, 25, and 35°C were -0.0076 (r^2 = 0.95), -0.01 (r^2 = 0.96), and -0.0131 (r^2 = 0.86), respectively. Equation (4) appears to be a zero order-type reaction even if different intercepts values. Intercept values are larger than those of rate constant, but those values are almost constant (0.49± 0.035). If the relationship is similar to zero order-type reaction, PC1 of equation (1) can be simplified into $(PC1)_{app}$.

Table 1. Rate constant and intercept of the relationship between PC1 and storage time

Storage temperature(°C)	Rate constant(hr^{-1})	Intercept	r^2
5	-0.0015[1)]	+ 0.52	0.88
15	-0.0076[1)]	+0.44	0.95
25	-0.01[1)]	+0.49	0.96
35	-0.0131	+0.51	0.87
		0.49±0.035	

[1)]The data obtained from the previous paper(8).

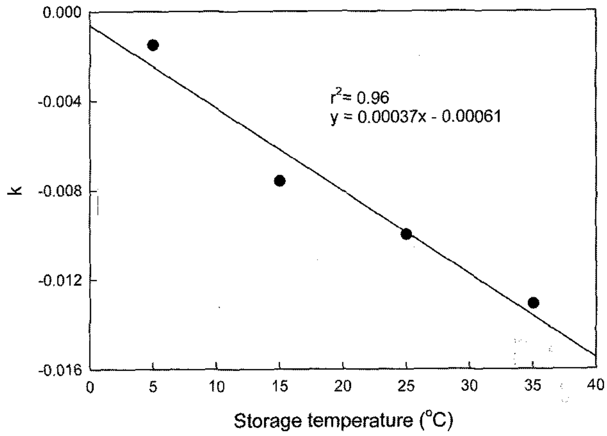

Fig. 1. The relationship between rate of constant and storage temperature for soybean curd. Rate constants at 5, 15, and 25°C were obtained in the previous paper (8).

To obtain a rate constant at an untested temperature, correlation between the rate constant and storage temperature was plotted. The rate constant (k) and storage temperature showed a good correlation (Fig. 1). Rate constant at 4 and 10°C (k_4 and k_{10}, respectively) not experimentally obtained were calculated on the basis of the linear equation. Changes in the freshness at 4 and 10°C for 48 hr could be predicted based on the obtained rate constant from Fig. 1 and equation (2).

Series of time-temperature-tolerance studies described by Guadagni (12) showed the shelf life of frozen food was related to the storage temperature. Results obtained from electronic nose analysis were compared with the predicted values (Fig. 2). The percentages of difference between the predicted and the actual values of the stored soybean curd were calculated on the basis of the predicted value at various storage times. The average differences were less than 8.9% under the fluctuating temperature condition. The good agreement observed between the predicted and the determined results indicated that the model was well fit for the prediction of the freshness of soybean curd.

In general, a single compound such as ascorbic acid has been used for kinetic analysis. Arrhenius model has been used for the determination of shelf life depending upon the temperature, and the principal component analysis (PCA) was applied for the prediction of freshness instead of using a single compound. Because PCA is a means of reducing the complex data into a less complex and the most significant component, we assumed that PCA was performed to

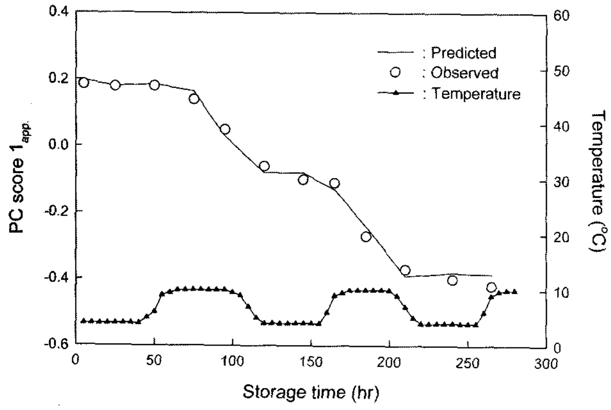

Fig. 2. The relationship between apparent first principal component score $(PC1)_{app}$ and storage time at fluctuating temperature condition. The predicted value means that the value was obtained from kinetic equation while the observed value was determined by electronic nose.

establish simple categories for the state of the freshness of soybean curds. PCA generally observed the patterns in the GC or sensory evaluation and reduces the number of dimensions to simplify interpretation (13).

In conclusion, electronic nose used in this study could be used as an efficient method to predict the freshness of soybean curd. The technique of using an electronic nose made possible the prediction of the freshness of soybean curd even under fluctuating temperature condition. PCA data can also be applied to kinetics analysis.

Acknowledgments

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