Construction of Shelf-Life Prediction Model for Golden Delicious Apple Based on Electronic Nose

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Abstract. The Golden Delicious apple shelf-life prediction model based on electronic nose was built by partial least squares regressions (PLSR). Sensory quality, such as, weight loss, texture, color changes and electronic nose were studied. The correlation between the electronic nose sensors and the sensory quality of Golden Delicious apples were analyzed to select the appropriate sensors for the construction of the shelf-life model. The results of the shelf-life prediction model on Golden Delicious apples building by PLSR showed that $R^2$ of training set was 0.86, RMSEC was 3.94. The $R^2$ of prediction set reached to 0.98, and the model was relatively accurate.

Keywords: Apple, Shelf-life, Model.

1. Introduction

Apple is considered to be one of the most widely cultivated fruits in the world [1]. It is also one of the fruits with the highest consumption and that people eat most commonly [2, 3]. Nowadays, researchers mainly focused on the effects of storage on the quality, flavor components and the comparison of quality differences. Few researches studied the correlation between quality and flavor substances during storage and evaluated fruits shelf-life. Most of the shelf-life prediction models of fruits were mainly constructed at different storage time, humidity and temperature, by measuring quality indexes, such as rot index, to build a dynamic prediction model, and then verified it. However, physical and chemical detection methods have disadvantages like low efficiency and destruction of samples [4, 5], therefore, rapid detection of fruit and vegetable quality became more and more popular. Electronic nose, as one of the rapid detection methods of food flavor, has the advantages of rapid detection, nondestructive detection and labor-saving [6, 7], and gained more and more attention in recent years. In this study, the Golden Delicious apples stored at 4°C were sampling for construction of shelf-life prediction model, and key electronic nose sensors were selected by correlation analysis with other apple quality indicators. This study could provide some theoretical reference on non-destructive and fast judgment of apple shelf-life.
2. Materials and methods

2.1. Materials
The Golden Delicious apples were hand-harvested from a commercial orchard in Jinzhou, Liaoning Province, China. All apples were stored at 4°C. Random samples were taken for determination during storage once a week.

2.2. Weight loss
Fifteen fruits were measured and averaged. The formula of weight loss rate is as follows.

\[
\text{Weightloss}(\%) = \frac{\text{Original mass} - \text{Final mass}}{\text{Original mass}} \times 100\%
\]  

(1)

2.3. Texture determination
The texture of the apple was measured using TA-XT-PLUS texture analyzer. Apples were cut into 1.5 × 1.5 × 2 cm samples for testing. The configuration parameters were set as follows: P/2 probe, pre-test speed 1.00 mm/s, test speed 1.00 mm/s, post-test speed 1.00 mm/s, measurement distance 5 mm.

2.4. Chromatic aberration
The chromatic aberration of apple was measured with CR-400 colorimeter. Colors are represented by \(L^*, a^*,\) and \(b^*\), representing luminance, chromaticity on the green (−) to red (+) axis, and chromaticity on the blue (−) to yellow (+) axis, respectively \[8\]. The total chromaticity change (\(\Delta E^*\)) is calculated according to formula (2).

\[
\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}
\]  

(2)

2.5. Electronic nose
PEN3 electronic nose was used to determine: apples were made into juice, put 15 mL of apple juice into a 50 mL calibrated centrifuge tube sealed with four layers of plastic wrap, placed at room temperature for 30 min, and repeated the experiment for 3 times. The cleaning time of the electronic nose was 100 s, and the detection time was 120 s. The flavor component information of apple juice was analyzed by Win-Muster software.

2.6. Statistical analysis
One-way ANOVA test and correlation analysis (Pearson correlation) were performed between apple quality indexes and E-nose sensors. The partial least squares regression (PLSR) was using the Unscrambler 9.7 software to construct the model.

3. Results and Discussion
Fig. 1 (A) showed the change of weight loss rate of Golden Delicious apples during storage. The weight loss rate increased gradually with increasing storage time. As shown in Fig. 1 (B), the hardness of both peel and flesh of Golden Delicious apples presented a decreasing trend along with storage time increasing.
Figure 1. Weight Loss (A) and texture changes (B) of Golden Delicious apples during storage

The value of $\Delta E^*$ represents the total color difference, and the larger the value, the greater the color change. From Table 1, the total color difference of Golden Delicious apples pericarp was significantly different from that at the early stage $(P < 0.05)$.

Table 1. Changes on color difference of Golden Delicious apples during storage

| Storage time (d) | $L^*$    | $a^*$    | $b^*$    | $\Delta E^*$ | $h^*$    | $C^*$    |
|------------------|---------|---------|---------|--------------|---------|---------|
| 0                | 83.13±0.70bc | -12.18±0.73j | 42.15±2.48h | 87.97±1.29h | 106.14±0.96a | 43.88±2.48g |
| 5                | 83.82±1.17a | -11.59±0.63g | 43.53±3.27g | 89.13±1.78g | 105.00±1.50b | 45.06±3.11g |
| 10               | 83.79±0.81a | -11.96±0.64j | 45.40±2.10h | 89.94±1.01f | 104.78±0.95b | 46.95±2.05f |
| 15               | 83.07±0.96bc | -10.99±0.50fh | 46.81±2.34g | 89.86±1.51f | 103.27±1.19e | 48.09±2.18ef |
| 20               | 83.36±0.89h | -10.89±0.43fh | 47.39±1.89g | 90.37±0.94ef | 102.97±0.96e | 48.63±1.76e |
| 25               | 82.75±0.53cd | -10.74±0.79fh | 51.30±2.29g | 91.74±1.12ed | 101.85±1.05d | 52.43±2.22c |
| 30               | 82.90±0.70c | -10.33±0.52g | 50.06±3.11f | 90.97±1.38de | 101.72±1.23d | 51.13±2.96d |
| 35               | 82.23±0.62ef | -11.10±1.25h | 52.62±2.70e | 92.01±1.45bc | 101.94±1.52d | 53.79±2.61b |
| 40               | 81.72±0.52d | -11.15±1.33h | 52.72±2.74e | 91.64±1.52cd | 101.99±1.71e | 53.91±2.57b |
| 47               | 81.53±0.57gh | -9.80±1.44ef | 53.73±2.05de | 91.88±0.97bc | 100.38±1.75ef | 54.64±1.86g |
| 54               | 81.82±0.35fg | -10.58±1.21eh | 55.29±1.80abc | 93.03±1.05a | 100.86±1.40ae | 56.31±1.66a |
| 61               | 80.97±0.50b | -9.53±1.57g | 55.69±1.94a | 92.44±1.19ab | 99.73±1.69c | 56.52±1.85a |
| 68               | 81.11±0.70b | -9.44±1.47g | 55.86±1.77a | 92.65±1.31ab | 99.61±1.58fg | 56.67±1.69a |
| 75               | 80.73±0.87b | -8.61±1.70e | 55.56±1.70ab | 92.10±1.47bc | 98.81±1.77bc | 56.25±1.66a |
| 82               | 78.10±1.35b | -6.21±2.45e | 54.31±1.44bcd | 49.29±1.63b | 96.54±2.60e | 54.72±1.35b |
| 89               | 77.59±0.27b | -5.52±0.98b | 53.65±1.73cd | 48.77±1.66d | 95.88±1.10e | 53.94±1.69b |
| 96               | 74.61±0.44b | -1.98±0.51b | 54.12±2.33ed | 50.40±2.04d | 92.11±0.60e | 54.16±2.32b |

Different superscripts (a-k) indicate significant differences $(P < 0.05)$ at a same column for a certain quality attribute.

Fig. 2 showed the principal component analysis and load diagram changes of Golden Delicious apples during storage. Fig. 2-A showed that the contribution rate of the first principal component was 99.56%. Hence, from PCA1, the aroma components of Golden Delicious apples changed significantly under different storage time, especially at early stage.
As shown in Fig. 3, the E-nose sensor of R9 showed little correlation with other quality indexes, while other sensors more or less correlated with some quality indicators. So, the Golden Delicious apples shelf-life prediction model was constructed by the 9 key E-nose sensors (except R9).

In the process of building the PLSR prediction model, 9 key sensors of the electronic nose were taken as the independent variable, and the storage time was taken as the dependent variable. The electronic
nose response values measured during the storage period were selected as the prediction set to verify the model.

The parameter of PLSR prediction model for the shelf-life model of Golden Delicious apples are shown in table 2, and this model has a good prediction accuracy. Fig. 4 is the fitting result of the predicted and measured values. It could be seen from table 2 and fig. 4 that $R^2$ of the shelf-life prediction model training set was 0.86 and RMSEC was 3.94. Using this model to predict the shelf-life, $R^2$ was 0.98. Therefore, the PLSR shelf-life prediction model of Golden Delicious apples based on electronic nose was relatively accurate ($R^2 > 0.80$).

**Table 2.** Parameter of shelf-life of Golden Delicious apples based on electronic nose sensor signal by PLSR

|                   | Training set | Prediction set |
|-------------------|--------------|----------------|
| $R^2$             | 0.86         | 0.98           |
| RMSEC             | 3.94         | 3.83           |

**Figure 4.** Correlation between measured and predicted values from PLSR model for shelf-life of Golden Delicious apples.

4. Conclusion
Correlation analysis of electronic nose sensor and sensory quality of Golden Delicious apples were studied. The shelf-life prediction model of Golden Delicious apples was constructed by 9 sensors of the electronic nose (except R9). The results of PLSR prediction model showed that $R^2$ was 0.86 and RMSEC was 3.94. Using this model to predict the shelf-life, $R^2$ was 0.98. This showed that the model was relatively accurate.

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