Advance Journal of Food Science and Technology 12(11): 635-643, 2016
DOI:10.19026/ajfst.12.3322
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: April 11, 2016 Accepted: June 4, 2016 Published: December 15, 2016

Research Article

Fruit Surface Color Recognition of Postharvest Litchi during Storage Based on Electronic Nose

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Abstract: An electronic nose and a colorimeter were used to sample post-harvest litchis stored in three different storage environments (room temperature, refrigerator and controlled atmosphere) in order to explore the feasibility of electronic nose for fruit surface color recognition. BP Neural Network (BPNN), Simple Correlation Analysis (SCA), Canonical Correlation Analysis (CCA) and Partial Least Squares Regression (PLSR) were used for data processing. The experimental results demonstrate that with the increasing of storage time, the rate of decrease of color values (L*, a*, b*) is the fastest for litchis stored at the room temperature, followed by litchis stored in a refrigerator environment and a controlled atmosphere environment. During storage, the change in sensors' response is the fastest for litchis stored at room temperature, followed by litchis stored in a refrigerator environment and litchis stored in a controlled atmosphere environment. The BPNN can effectively classify the storage time of litchis stored in a refrigerator environment and in a controlled atmosphere environment. However, the BPNN classification effect for litchis stored at room temperature is poor. Both of the CCA and the SCA results show that a certain correlations exists between the surface color values of litchi and the electronic nose response of litchi. The PLSR result shows that the prediction effect of surface a* prediction in litchis stored in a refrigerator environment is good. This research demonstrates the feasibility of the electronic nose for fruit surface color recognition, thereby providing a reference for fruit quality monitoring.

Keywords: Artificial olfactory, classification and recognition, electronic nose, litchi, storage, surface color

INTRODUCTION

The decay rate of postharvest litchis is very fast. As the saying goes (Qian *et al*., 2011), "if stored at room temperature after harvesting, litchi's color will be changed in the first day, its fragrance will be changed in the second day, its flavor will be changed in the third day and all the color, fragrance and flavor will be lost before the fifth day." From a statistical perspective, the number of litchis lost due to decay constitutes more than 20% of the total number of litchis lost each year in China (Lai and Ao, 1998). The surface color is an important reference for evaluating the quality of fruits. It is also an important characteristic reflecting the state of decay of the litchi. Changes of surface color usually have the direct influences on the commodity value. The surface color of fruits is usually expressed as L*, a* and b*(Mogol and Gökmen, 2014; Pathare *et al*., 2013). Previously research results show that when the browning area of the litchi surface is between the range of slight browning to the 1/4th of the total surface area, its flavor is influenced significantly, the rate of loss of soluble solid flavor increases significantly and the quantity of sale is decreased (Zhou *et al*., 2012). Thus, the surface color of the litchi highly influences its quality and commodity value. For this reason, it would be helpful to recognize and locate the litchi's surface color accurately and rapidly, which helps to gauge and monitor the quality of the litchi during storage and transportation and to provide a reference for consumers shopping these litchis.

The surface color change in post-harvest litchis is called browning, which is mainly caused by fast water loss (Riederer *et al*., 2015). Currently, the sensory evaluation method is the main method of litchi browning recognition (Yang *et al*., 2014). In this method, testers recognize litchi's browning with the help of the magnifying glass. The sensory evaluation method is time consuming, requires a high labor force andiseasily influenced by subjective factors. Yang *et al*.

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(2015) have used hyperspectral imagery technology to recognize the browning of litchis. However, it was only a preliminary research to demonstrate the feasibility of hyperspectral imagery technology for recognition of browning in litchis. Additionally, the limited field angle is a significant flaw when using hyperspectral imagery technology to recognize the browning of litchis. Thus, finding a rapid and effective way for surface color recognition still remains a significant challenge.

As the detection mean simulates biological olfaction, electronic nose sampling works by recording the response of its sensor array when brought into contact with volatiles of the sample (Roy *et al*., 2012). Electronic nose detection is not influenced by subjective factors and is not limited by the field angle. Thus, electronic nose has extensive application prospects in fruit quality detection (Baietto and Wilson, 2015; Pan *et al*., 2014). However, research about fruit surface color recognition based on the electronic nose method has not yet been reported.

There have been a few reports which show that it is feasible to use an electronic nose to recognize volatiles in litchis (Pan *et al*., 2012; Xu *et al*., 2015a; Ying *et al*., 2015). Additionally, our previous research also shows high correlations between the electronic nose response data of litchi and the physicochemical indexes of litchi (Xu *et al*., 2015b). Thus, the existing research provides a theoretical basis for fruit surface color recognition by use of an electronic nose. Therefore, the question of whether fruit surface color of litchis can be recognized by an electronic nose during storage is worthy of further research.

This study explored the feasibility of using an electronic nose for litchi surface color recognition. An electronic nose was used for the sampling of litchis stored in three different environments (room temperature, refrigerator and controlled atmosphere). In parallel, a colorimeter was also used to acquire the color values of the litchi samples. BP neural network (BPNN), simple correlation analysis (SCA), Canonical Correlation Analysis (CCA) and Partial Least Squares Regression (PLSR) were used for data processing. This research may provide a reference for fruit surface color recognizing and quality monitoring.

MATERIALS AND METHODS

Experimental materials and processing: The experimental litchi samples were of the Guiwei type (80 to 90% maturity). All litchi samples were harvested from the Conghua litchi orchard in Guangzhou, China in June 2016 and transported to the College of Engineering, South China Agricultural University, Guangzhou, China within 2 h. After removing the fruit spurs and selecting nondestructive litchi samples for the experiment, these samples were divided into 3 groups (room temperature group, refrigerator group and controlled atmosphere group). Cold water (made by mixing ice and water, 4 to 5°C) was used forpre-cooling (Ruan *et al*., 2012) before litchis to be stored in a refrigerator environment and a controlled atmosphere environment. Because the decay speed of litchis will increases if they are moved from a cold to a warm environment after pre-cooling (Chen *et al*., 2001). Thus, the litchi samples stored in the room temperature environment were not pre-cooled in this experiment. Perforated polyethylene bags with a perforation ratio of 5% and a size of 300×200×0.05 mm were used to pack the litchi samples, with 30 litchis per bag. After this step, all of the packed samples were putted into plastic crates and stored in different environments. The room temperature storage environment was kept at 25°C; the refrigerator storage environment was kept at 3-5°C; while the controlled-atmosphere storage environment was kept at 3-5°C, 90-95% relative humidity and 3-6% oxygen content.

Because of the decay, the whole surface of litchis stored in the room temperature environment usually browned completely within six days after harvesting (Zhou *et al*., 2012). However, the refrigerator storage environment (Shah and Nath, 2006) and controlled-atmosphere storage environment (Mahajan and Goswami, 2004) can restrict the browning of litchis to a certain degree and could extend the litchis' freshness lifetime. Thus, in this experiment, litchis stored in the room temperature were tested at the storage times of the 0th, 1st, 2nd, 3rd, 4th and 5th day and litchis stored in the refrigerator storage environment and controlled-atmosphere storage environment were tested at the storage times of the 0th, 3rd, 6th, 9th, 12th and 15th day. Twenty electronic nose data and 20 color value data were sampled for each storage environment at each sampling time. Thus, 120 electronic nose sampling data and 120 color value sampling data were acquired for each of the three storage environments.

Storage equipments: An air conditioner (KFR-72LW, Gree Ltd., China), refrigerator (GX, Guangxiang Ltd., China) and our laboratory-developed controlled-atmosphere storage platform (Xu *et al*., 2012) were used as the storage equipment for room temperature storage, refrigerator storage and controlled atmosphere storage, respectively. The performance of the laboratory-developed controlled-atmosphere storage platform was proven to be reliable and its interior temperature could be adjusted as the requirements of experiment.

Sampling methods:

Color value sampling: To determine the color of litchis, a fully automatic colorimeter (CR-400, Konica Minolta Ltd., Japan) was used to acquire the fruit surface color values (L*, a* and b*). L* indicates surface brightness or darkness; a* indicates how red or green the surface of the litchi is; and b* indicates how

blue or yellow the surface of the litchi is. Thecolor measurement was recorded at the "equator" of each litchi sample and their average value was counted as the color value.

Electronic nose sampling: A portable electronic nose (PEN3, AIRSENSE Ltd., Germany) was applied to sample the change in volatiles of litchis stored in the three environments. The sensor array of the electronic nose includes 10 metal oxide gas sensors (Macías *et al*., 2013). Each sensor is sensitive to a different type of volatile, which makes the whole electronic nose capable of recognizing various smells.Each sample (includesone litchi fruit) was placed in a 200-mL glass breaker and sealed with double-deck plastic films. After 0.5 h, electronic nose was used to sample the headspace gas of the litchi sample. Beakers were washed using an ultrasonic cleaning instrument and cooled in the shade and no peculiar aroma was detected environment. Before sampling, zero gas (room air that had been filtered through standard activated carbon) was pumped into the cleaning channel to normalize the sensors. The operating parameters of the electronic nose were: sampling interval was 1 s; flush time was 60 s; zero point trim time was 10 s; measurement time was 80 s; pre-sampling time was 5 s; and injection flow was 300 mL/min. The 80th response value of each sensor was extracted as the feature value for the next data analysis.

Data processing methods:

BPNN: BPNN can be described as a non-linear projection between the input vectors and output vectors. A typical BPNN structure has three parts: one input layer, one hidden layer and one output layer. In the process of training BPNN for analysis, the weights and threshold values of each layer are revised constantly. This training lasts until the difference between the expected outputs and actual outputs is limited to a preliminary range, or until the scheduled training times are achieved (Zhang *et al*., 2013).

SCA: SCA is a statistical approach usually applied for measuring the relationship between two variables. When comparing the correlation between two variables, one variable is called the "dependent" variable while the other is the "independent" variable. The goal is to see if a change in the independent variable (which is usually an indicator) will result in a change in the dependent (Sysoev *et al*., 2006).

CCA:CCA can focus on the relationship between two groups of variables. The analysis process of CCA is to build a linear combination for each group of variables based on the total variation of their original data matrixes, find the most relevant aggregate variable (canonical correlation variable) from the linear combinations and then, reveal the related properties of the two groups of variables via the canonical correlation variable (Aleixandre *et al*., 2015).

PLSR: The PLSR technique is usually used to build a model for each predicted property. This method is based on multiple linear regressions and is suitable for large problems where the amount of computation with standard methods of matrix inversion or diagonalization becomes prohibitive. PLSR produces a technique that is able to accept collinear data and separate out the sample noise in order to make linear combinations in the dependent concentration matrix (Qiu *et al*., 2014).

RESULTS AND DISCUSSION

The surface color change of litchis stored in 3 different environments:

The L* change of litchis stored in 3 different environments: With increasing storage time,Changes in L* for litchis stored in 3 different environments are shown in Fig. 1. At the 0^{th} d, the difference in L* for litchis stored in each environment were small. After the 0^{th} d, the L* of the litchis stored in three environments were decreased with increasing storage time. However, the rate of decrease for litchis stored in the room temperature environment was the fastest followed by litchis stored in a refrigerator environment andthe litchis stored in a controlled-atmosphere environment.

The a* change of litchis stored in three different environments: The changes in a* for litchis stored in three different environments are shown in Fig. 2. The value of a* for litchis stored in the room temperature environment (at the 0^{th} d) was smaller than litchis stored in a refrigerator environment and in a controlled-atmosphere. The reason may be that the browning rate of litchis stored at room temperature was very fast, thus the a* of these litchis decreased within a short time. With increasing storage time, the a* of litchis stored in the room temperature environment decreased rapidly. However, the a* of litchis stored in a refrigerator environment changed little between the 0^{th} d and the 9^{th} d and then decreased rapidly after the 9^{th} d. The a* of litchis stored in a controlled-atmosphere environment changed little even in 15 days.

The b* change of litchis stored in 3 different environments: The change of b* in litchis stored in three different environments are shown in Fig. 3. At the 0th d, the b* of litchis stored in each storage environment were small. With the increase of storage time, the rate of decrease of b* was the fastest for litchis stored in room temperature, followed by litchis

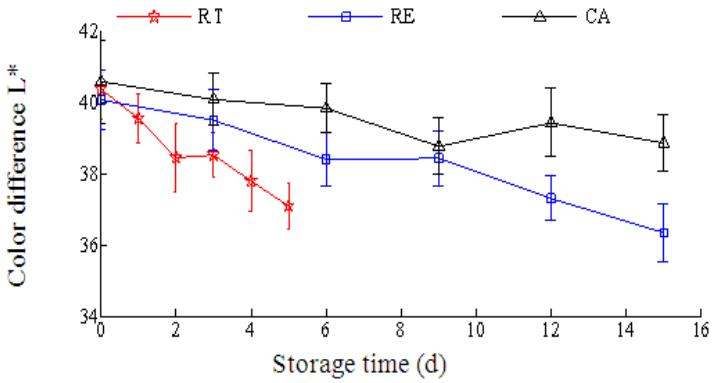


Fig. 1: Color difference value L* change of 3 environments stored litchi; RT is room temperature environment storage, RE is refrigerator environment storage, CA is controlled atmosphere environment storage, which is the same with figures below

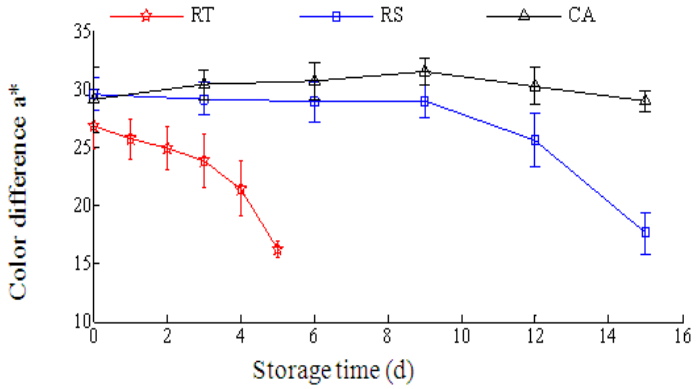


Fig. 2: Color difference value a* change of 3 environments stored litchi; RT is room temperature environment storage, RE is refrigerator environment storage, CA is controlled atmosphere environment storage, which is the same with figures below

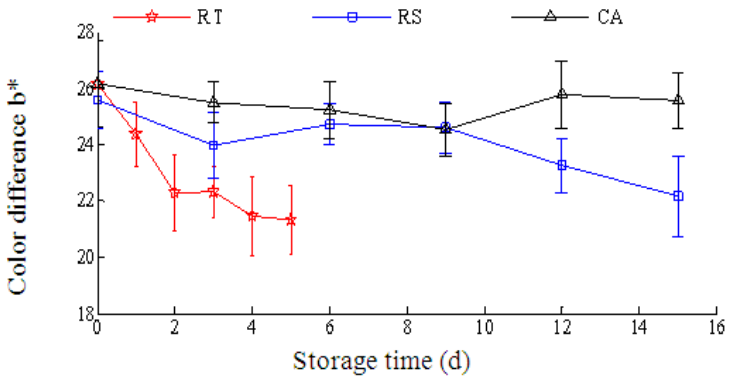
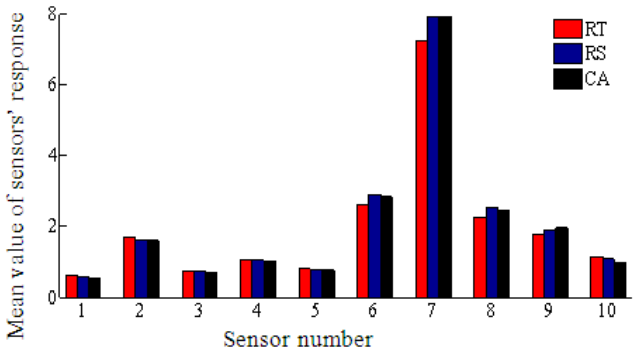


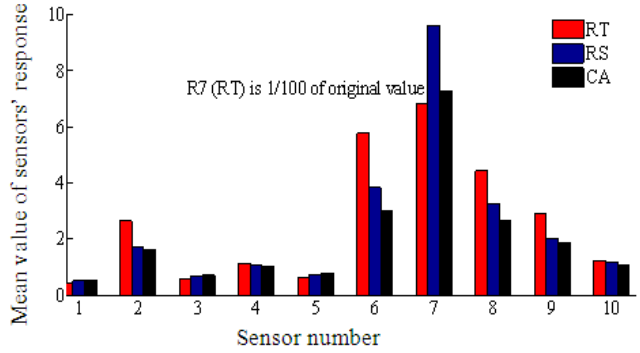
Fig. 3: Color difference value b* change of 3 environments stored litchi; RT is room temperature environment storage, RE is refrigerator environment storage, CA is controlled atmosphere environment storage, which is the same with figures below

stored in a refrigerator environment and litchis stored in controlled-atmosphere environment. The change of b* for litchis stored in the controlled-atmosphere environment was slight from the 0th d to the 15th d and the associated variation trend was not obvious. The b* of litchis stored in a refrigerator environment changed little from the 0th d to the 9th d, but decreased after the 9th d. The b* of litchis stored at room temperature was decreased throughout the storage period.

Change in electronic nose response of litchis stored in 3 different environments: To explore the feasibility of using an electronic nose to detect changing volatiles of the litchi fruit during storage, the average values of response value of each sensor for litchis stored in the three environments at the 0th d and at the 3rd d were shown in Fig. 4. The average sensor responses of litchis stored in the three environments on the 0th day are shown in Fig. 4a. On the 0th day, there were small



(a)



(b)

Fig. 4: Electronic nose response change of 3 environments stored litchi

differences in average sensor response for the 3 environments. The averages sensor responses of litchis stored in the three environments on the 3rd day are shown in Fig. 4b. The response value of the R7 sensor litchis stored in at room temperature (Fig. 4b) is the $1/100^{th}$ of the original value because the original value was too large to be conveniently shown in scale. The responses of sensors R2, R4, R6, R7, R8, R9 and R10 increased with the increase of storage time. However, the responses of R1, R2 and R5 decreased with the increase of storage time. In addition,the sensor responses show different gradients for litchis stored in room temperature environment, refrigerator environment and controlled atmosphere environment i.e., the sensors response was fastest for litchis stored in the room temperature environment, followed litchis stored in those for a refrigerator environment and controlled atmosphere environment. Thus, electronic nose could effectively recognize the change of volatiles in litchis during storage.

BPNN for storage time of litchis stored in 3 environments: To explore the recognition of changes in litchivolatiles, BPNN was used for storage time recognition of litchis stored in the 3 different environments. There were 120 electronic nose sampling data be acquired for each storage environment at five different storage times. Fifteen samples were randomly chosen from the data of each sampling time for each environment as the training set, while the remaining five samples as the test set. Thus, there were a total of 90 training set samples and 30 test set samples for each storage environment. The expected outputs for each storage times in each order were in the order (0, 0, 0), (0, 0, 1), (0, 1, 0), (1, 0, 0), (1, 0, 1) and (1, 1, 1). After training repeatedly, BPNN results of the storage times for litchis stored in the three environments after repeated training are shown in Table 1. The BPNN classification accuracies of storage times for training sets litchis stored in room temperature, refrigerator and controlled atmosphere environment were 88.89, 95.56 and 100%, respectively, while the corresponding values for the test set litchis stored in were 50, 80 and 86.67%, respectively. Thus, BPNN is an effective method to classify the storage time of litchis stored in the refrigerator and controlled atmosphere environments. However, the BPNN classification effect for storage times of litchis is poor at room temperature.

Correlation analysis between electronic nose sensors' response with litchi's color values:

SCA results: The SCA method was used to analyze the correlation between the sensor response of the electronic nose and the color change (L*, a* and b*) of

Table 1: BPNN classification of storage times for different storage environments

		Accuracy	
Storage environments	Learning rate/dynamic factor/maximum iterations	Training set	Test set
Room temperature	0.05/0.8/20000	88.89%	50%
Refrigerator	0.045/0.75/20000	95.56%	80%
Controlled atmosphere	0.035/0.9/20000	100%	86.67%

Table 2: The SCA results for Pearson correlation coefficients between each sensor's response and chromatic aberration indexes of 3 environments stored litchi

SE	Color	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
RT	L*	0.514	-0.451	0.518	-0.259	0.517	-0.502	-0.260	-0.477	-0.497	0.010
	a*	0.414	-0.505	0.455	-0.093	0.462	-0.410	-0.327	-0.350	-0.549	0.225
	b*	0.474	-0.412	0.477	-0.253	0.477	-0.464	-0.2248	-0.438	-0.455	-0.004
RE	L*	0.310	-0.100	0.328	-0.165	0.332	-0.242	-0.0754	-0.238	-0.200	0.072
	a*	0.429	-0.305	0.451	-0.101	0.474	-0.321	-0.1695	-0.283	-0.466	0.402
	b*	0.293	-0.125	0.295	-0.188	0.297	-0.216	-0.0500	-0.227	-0.222	0.097
CA	L*	0.311	-0.318	0.327	-0.094	0.325	-0.317	-0.1420	-0.307	-0.241	-0.242
	a*	-0.104	0.119	-0.120	-0.099	-0.111	0.091	0.0507	0.111	0.039	0.226
	b*	0.194	-0.220	0.194	0.053	0.189	-0.200	-0.1141	-0.219	-0.164	-0.279

SE: Storage Environment, RT: Room Temperature environment storage, RE: Refrigerator Environment storage, CA: Controlled Atmosphere environment storage, R_n; The n^{th} sensor of the sensor array of electronic nose

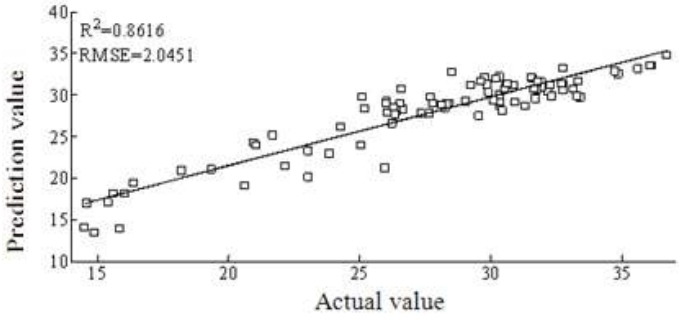
Table 3: Canonical correlation analysis between chromatic aberration indexes and sensor array's response

	Room temperature			Refrigerator			Controlled atmosphere		
Storage environments									
Color	L*	a*	b*	L*	a*	b*	L*	a*	b*
Canonical correlation coefficient	0.364	0.464	0.322	0.181	0.666	0.180	0.186	0.149	0.145

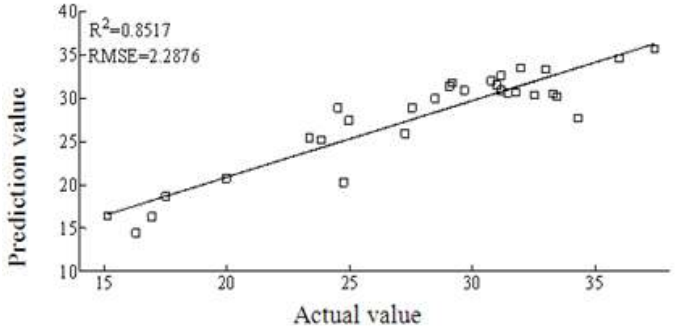
litchis stored in the three environments. The Pearson's correlation coefficient (r) is an important parameter to assess the degree of correlation when using the SCA analysis. The definitional domain of r is [-1, 1]. A positive rvalue implies positive correlation and a negative value implies negative correlation. Generally, $0 \leq |r| < 0.4$ implies low correlation, $0.4 \leq |r| < 0.7$ implies significant correlation and $0.7 \leq |r| \leq 1$ implies that the correlation is highly significant (Ren, 2013). The SCA results for correlations between each sensor response and the corresponding color value are shown in Table 2. For litchis stored in the room temperature environment, the change of L* of litchi surface was highly correlated to the responses of R1, R2, R3, R5, R6, R8 and R9; the change of a* of litchi surface was highly correlated to the responses of R1, R2, R3, R5, R6 and R9; and the change of b* of litchi surface was highly correlated to the responses of R1, R2, R3, R5, R6, R8 and R9. For litchis stored in a refrigerator environment, both L* and b* were weakly correlated to the response of each sensor; however, the change of a* was highly correlated to the responses of R1, R3, R5, R9 and R10. For litchis stored in a controlled-atmosphere, L*, a* and b* were all weakly related to the response of each sensor.

CCA results: Because ofSCA can only detect the correlation between a single sensor response and a single color value of litchi. Thus, CCA analysis was used to explore the correlation between each color value with the whole response of the electronic nose sensor array and these results are shown in Table 3. The values of a* were correlated to the whole response of the electronic nose array for litchis stored in the room temperature environment and litchis stored in a refrigerator environment, with correlation coefficients of 0.464 and 0.666, respectively (correlation coefficient>0.4). The other color values were weakly related to the whole response of the electronic nose sensor array.

PLSR for the prediction of color value of litchi surface: The experimental results indicate that there was a relatively high correlation between a* and the whole sensor response for litchis stored in a refrigerator environment. Thus, PLSR was applied to explore the feasibility of color prediction based on an electronic nose. This experiment takes the response data of the whole sensor array as the input data, while a* of litchis stored in a refrigerator environment is taken as the target output. Fifteen samples were randomly chosen as the training set at each storage time for litchis stored in each storage environment, while the remaining five samples formed the test set at each storage time for litchis stored in each storage environment. Thus, each storage environment has 90 training set samples and 30 test set samples. R^2 and RMSE are the two important indexes for judging the imitative effect of PLSR results. Generally, if $R^2>0.8$ implies that the prediction values were high related to the actual values and that the prediction effect is good. If R^2 is approaches1 or 0, this means that the prediction effect is good or bad, respectively. A value of RMSE close to 0 implies a better prediction effect. A value of RMSE close to 1 implies a bad prediction effect. The PLSR prediction



(a)



(b)

Fig. 5: The a* prediction of refrigerator environment stored litchis, based on PLSR

results of litchi color are shown in Fig. 5. The a* PLSR results for the training set of litchi samples stored in a refrigerator environment are shown in Fig. 5a, for which the R^2 and RMSE of it were 0.8616 and 2.0451, respectively. The a* PLSR results for the test set of litchi samples stored in refrigerator environment are shown in Fig. 5b, for which R^2 and RMSE of it were 0.8571 and 0.2876, respectively. Thus, the electronic nose shows a good prediction effect of litchi color (the R^2 of both training set and test set are greater than 0.8). Therefore, it is feasible to use an electronic nose to predict the surface color of litchi fruit.

DISCUSSION

This experiment explored the feasibility of fruit surface color recognition of litchis stored in different environments by electronic nose. The experimental results demonstrated that sampling data obtained with the electronic nose were correlated with the color value of litchi surface and it is thus feasible to use an electronic nose for surface color recognition of litchis.

An electronic nose can effectively classify the storage time of litchis stored in a refrigerator environment and a controlled-atmosphere environment. However, the classification effect of storage times is poor for litchis at room temperature. We can infer that this finding may be observed because the qualitative rate of change of litchi samples stored at room temperature is relatively fast, which results in relatively large differences in litchi samples stored at room temperature, even for at the same storage time. However, the other environments (a refrigerator environment and controlled-atmosphere environment) are better than room temperature for preserving the freshness and characteristics of litchis, so that the qualitative rates of change for litchis stored in other environments are slower than for those stored at room temperature. Thus, the classifications of litchis stored in the two other environments are better than that for litchis stored in the room temperature environment.

SCA results show that L*, a* and b* of litchis stored in a room temperature environment and a* of litchis stored in refrigerator environment were high related with several single sensors, respectively. However, CCA results show that the whole response of sensor array was only related to a* of litchis stored in room temperature environment and refrigerator environment. The SCA is focus on the correlation between single variable, the CCA can focus on the correlation between aggregate variables.

PLSR results prove the feasibility of fruit color recognition of litchis by electronic nose. Research shows that when an aggregate variable composed of the

response of several single variables is used for classification and recognition, there is mutual coupling among different single variables. This mutual coupling can effectively decrease the influence of the fluctuation of some single variables and improve the recognition accuracy (Li *et al*., 2008). Thus, to better realize surface color recognition by electronic nose, future research can focus on finding e aggregate variables (composed of the response of several single sensors) which are highly correlated to the color index of litchis, meaning that such aggregate variables can be used to predict the other color indexes of litchis stored in different environments.

CONCLUSION

The objective of this study was to identify an effective way for rapid recognition of the surface color of postharvest litchis during storage. It was shown that an electronic nose may be used to solve this problem. The rate of decrease of surface color values (L*, a* and b*) was fastest for litchis stored in a room temperature environment, followed by that in a refrigerator environment and that in a controlled atmosphere environment. The responses of the sensors R2, R4, R6, R7, R8, R9 and R10 increased with an increase in storage time. However, the responses of R1, R2 and R5 decreased an increase in storage time. The rate of change of sensor response for was fastest for litchis stored in a room temperature environment followed by litchis stored in a refrigerator environment and litchis stored in a controlled atmosphere environment. The BPNN classification accuracy of storage times for training sets of litchis stored in room temperature, refrigerator and controlled atmosphere environments were found to be 88.89, 95.56% and 100%, respectively; while the corresponding values for the test set were found to be 50, 80 and 86.67%, respectively. Thus, BPNN can effectively classify the storage time of litchis stored in refrigerator and controlled atmosphere environments. However, the BPNN classification effect is poor for litchis stored at room temperature. SCA results showed that L*, a* and b* of litchis stored in a room temperature environment and a* of litchis stored in a refrigerator environment were correlated with several single sensor responses. However, CCA results showed that the whole response of the sensor array was only correlated with a* of litchis stored in a room temperature environment and in a refrigerator environment. The R^2 and RMSE values of the training set for fruit surface a* prediction of via PLSR were 0.8616, 2.0451, respectively, for litchis stored in a refrigerator environment. The R^2 and RMSE values of the test set were 0.8571 and 2.2876, respectively. Thus, it is feasible to use an electronic nose to recognize fruit surface color.

ACKNOWLEDGMENT

This research has received financial support from Natural Science Foundation of China (31571561).

REFERENCES

Aleixandre, M., J. Pedro Santos, I. Sayago, J. Mariano Cabellos, T. Arroyo and M. Carmen Horrillo, 2015. A wireless and portable electronic nose to differentiate musts of different ripeness degree and grape varieties. Sensors (Basel), 15(4): 8429-8443.

Baietto, M. and A.D. Wilson, 2015. Electronic-nose applications for fruit identification, ripeness and quality grading. Sensors (Basel), 15(1): 899-931.

Chen, H.G., Y.L. Wang and Y.H. Peng, 2001. Shelf-quality and physiological indices of litchi subjected to cool storage. Subtropical Plant Sci., 3(2).

Lai, N.J. and Q.Y. Ao, 1998. Advances in studies on postharvest physiology. Pathol. Preserv. Litchi Fruits, 3: 27-31.

Li, M., J.W. Xu, J.H. Yang and D.B. Yang, 2008. Prediction for chaotic time series based on phase reconstruction of multivariate time series. J. Univ., Sci. Technol. Beijing, 30: 208-211.

Macías, M.M., A.G. Manso, C.J.G. Orellana, H.M.G. Velasco, R.G. Caballero and J.C.P. Chamizo, 2013. Acetic acid detection threshold in synthetic wine samples of a portable electronic nose. Sensors (Basel), 13(1): 208-220.

Mahajan, P.V. and T.K. Goswami, 2004. Extended storage life of litchi fruit using controlled atmosphere and low temperature. J. Food Process. Pres., 28(5): 388-403.

Mogol, B.A. and V. Gökmen, 2014. Computer vision-based analysis of foods: A non-destructive colour measurement tool to monitor quality and safety. J. Sci. Food Agr., 94(7): 1259-1263.

Pan, C.H., H.Y. Hsieh and K.T. Tang, 2012. An analog multilayer perceptron neural network for a portable electronic nose. Sensors (Basel), 13(1): 193-207.

Pan, L.Q., W. Zhang, N. Zhu, S.B. Mao and K. Tu, 2014. Early detection and classification of pathogenic fungal disease in post-harvest strawberry fruit by electronic nose and gas chromatography-mass spectrometry. Food Res. Int., 62: 162-168.

Pathare, P.B., U.L. Opara and F.A.J. Al-Said, 2013. Colour measurement and analysis in fresh and processed foods: A review. Food Bioprocess Tech., 6(1): 36-60.

Qian, W., X. Wei and D. Shaobi, 2011. Development and application of ice bank precooling equipment used in litchi producing area. Proceeding of the International Conference on New Technology of Agricultural Engineering (ICAE, 2011). Zibo, pp: 1116-1120.

Qiu, S., J. Wang and L. Gao, 2014. Discrimination and characterization of strawberry juice based on electronic nose and tongue: Comparison of different juice processing approaches by LDA, PLSR, RF, and SVM. J. Agr. Food Chem., 62(27): 6426-6434.

Ren, Y.Z., 2013. Identification of almond cake deterioration based on computer olfactory. M.S. Thesis, Guangdong University of Technology, Guangdong, Guangzhou.

Riederer, M., K. Arand, M. Burghardt, H. Huang, M. Riedel, A.C. Schuster, A. Smirnova and Y. Jiang, 2015. Water loss from litchi (*Litchi chinensis*) and longan (*Dimocarpus longan*) fruits is biphasic and controlled by a complex pericarpal transpiration barrier. Planta, 242(5): 1207-1219.

Roy, R.B., B. Tudu, L. Shaw, A. Jana, N. Bhattacharyya and R. Bandyopadhyay, 2012. Instrumental testing of tea by combining the responses of electronic nose and tongue. J. Food Eng., 110(3): 356-363.

Ruan, W.L., B.L. Liu and X.Y. Song, 2012. Comparison of cooling method for litchi fruit. Sci. Technol. Food Ind., 11: 86.

Shah, N.S. and N. Nath, 2006. Effect of calcium lactate, 4-hexyl resorcinol and vacuum packing on physico-chemical, sensory and microbiological qualities of minimally processed litchi (*Litchi chinensis* Sonn.). Int. J. Food Sci. Tech., 41(9): 1073-1081.

Sysoev, V.V., B.K. Button, K. Wepsiec, S. Dmitriev and A. Kolmakov, 2006. Toward the nanoscopic "electronic nose": Hydrogen vs carbon monoxide discrimination with an array of individual metal oxide nano- and mesowire sensors. Nano Lett., 6(8): 1584-1588.

Xu, J.F., H.Z. Lu, E. Lü, G.H. Wang and X.T. Han, 2012. Design on an experimental platform with controlled atmosphere by liquid nitrogen injection for food transportation. J. Anhui Agr. Sci., 40(4): 144.

Xu, S., H. Lu, Z. Zhou, E. Lü and J. Yang, 2015a. Electronic nose monitoring mature stage of litchi in orchard. T. Chinese Soc. Agric. Eng., 31: 240-246.

Xu, S., H.Z. Lu, Z.Z. Zhou, E.L. Lü, Y.M. Jiang and Y.J. Wang, 2015b. Identification of litchi's maturing stage in orchard based on physicochemical indexes and electronic nose. T. Chinese Soc. Agric. Mach., 46: 226-232.

Yang, S., E. Lü, H. Lu, Z. Zeng and B. Tang, 2014. Effects of different fresh-keeping transportation modes on quality of litchi fruit. T. Chinese Soc. Agric. Eng., 30(10): 225-232.

Yang, Y.C., D.W. Sun and N.N. Wang, 2015. Rapid detection of browning levels of lychee pericarp as affected by moisture contents using hyperspectral imaging. Comput. Electron. Agr., 113: 203-212.

Ying, X., W. Liu and G. Hui, 2015. Litchi freshness rapid non-destructive evaluating method using electronic nose and non-linear dynamics stochastic resonance model. Bioengineered, 6(4): 218-221.

Zhang, L., F. Tian, S. Liu, J. Guo, B. Hu, Q. Ye, L. Dang, X. Peng, C. Kadri and J. Feng, 2013. Chaos based neural network optimization for concentration estimation of indoor air contaminants by an electronic nose. Sensor. Actuat. A-Phys., 189: 161-167.

Zhou, X.Z., Y. Chen, J.Y. Tang, S.F. Huang and Y. Cao, 2012. Loss estimation of litchi fruit due to pericarp browning. Chinese J. Trop. Crops, 33: 1403-1408.