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Prediction of egg storage time and yolk index based on electronic nose combined with chemometric methods

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ABSTRACT

Egg storage time and yolk index, two descriptors of egg freshness, were evaluated by an electronic nose combined with chemometric methods. To obtain more useful information from collected data, the wavelet energy was extracted as feature signal by the wavelet transform method for qualitative and quantitative analysis. For qualitative analysis, linear discriminant analysis (LDA) was applied to evaluate the feature signals, and the result indicated that these feature signals had good classification performance with the first two scores explaining 82.50% of total variance. Moreover, probabilistic neural network (PNN) was performed to classify eggs with different storage times, and 92.86% of samples in testing set were classified correctly. For quantitative analysis, back propagation neural networks (BPNN) and support vector machine (SVM) were applied to build prediction models of yolk index, indicating that SVM models ($R^2 = 0.9641$ in training set and $R^2 = 0.8339$ in testing set) were better than BPNN ($R^2 = 0.8629$ in training set and $R^2 = 0.7863$ in testing set). To further improve the performance of SVM models, independent component analysis (ICA) and local linear embedding (LLE) were used to reduce dimension of feature data, and the results showed that ICA-SVM model had satisfying prediction performance ($R^2 > 0.97$).

1. Introduction

Eggs have always been one of the most important food in our daily life. So far, there is much research conducted on detection of egg quality, concerning interior changes of eggs over storage. Typically, reduction of egg quality can be explained as the result of an enhanced interaction between lysozyme and ovomucin as pH increases during storage (Soltani & Omid, 2015). Although a method called ‘candling’ could offer to examine eggs by checking internal characteristics of egg on top of bright light shining (Wang & Jiang, 2005; Wang, Jiang, & Yu, 2004; Zhang, Pan, Tu, Zhan, & Tu, 2015), it would be so arduous that mistakes occur easily. Therefore, new detecting techniques are in great need to detect egg quality more efficiently.

Recently, many studies have been carried out to develop techniques for nondestructive detection of egg quality. Most of them focused on spectroscopic and optical methods. Near infrared reflection (NIR) spectroscopy is a fast and accurate technique for nondestructive detection, and it has been conducted to measure egg freshness by means of an FT-NIR spectrometer and a fiber optic probe (Giunchi, Berardinelli, Ragni, Fabbri, & Silaghi, 2008). Others combined the NIR technique with different data analysis methods like multivariate analysis (Lin, Zhao, Sun, Chen, & Zhou, 2011) and support vector data description (Zhao et al., 2010), all of which demonstrated the feasibility of detecting egg freshness by the NIR method. As for the optical method, Liu, Ying, Ouyang, and Li (2007) had investigated the potential of applying the ultraviolet and visible (UV/VIS 200–800 nm) transmittance method to inspect the internal quality of intact chicken egg, and reached the conclusion that the nondestructive inspection of egg freshness by transmittance properties is feasible in the range of 400–600 nm. Besides these major methods, dielectric properties of eggs have also been studied in determining egg quality. For instance, Soltani, Omid, and Alimardani (2015) developed an egg qualifying system based on dielectric technology. In evaluation of the qualifying system, the mean absolute percent errors obtained from testing sets were 5.41, 6.84, 8.79, and 4.24% for the Haugh unit, yolk index, yolk/albumen, and yolk weight, respectively. Evaluation results showed the designed device which was fabricated based on dielectric measurement and the machine vision technique could be confidently

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used in predicting egg quality indices.

Undeniably, these approaches present potential solutions for the nondestructive detection of egg quality. Yet there are two critical problems: first, eggshell may affect detection precision of these optical and spectroscopic methods; second, applicability of dielectric properties in detecting egg quality remains to be improved. So it is necessary to search for more efficient and economical ways to detect egg quality. Given that a change of egg quality will give rise to changes in its volatile gas components, an electronic nose system may be a potential alternative strategy for detecting egg quality by sensing its volatile profile. Actually, some researches have already proved the possibility of detecting egg quality with an electronic nose. Dutta, Hines, Gardner, Udrea, and Boilot (2003) employed an array of four tin oxide sensors to predict egg freshness, and suggested that eggs can be categorized into one of three states with up to 95% accuracy. Yongwei, Wang, Zhou, and Lu (2009) demonstrated the potential of monitoring internal quality of eggs during storage and established prediction models for quality indices. These studies provide references for determining egg quality by electronic nose.

Both Dutta et al. (2003) and Yongwei et al. (2009) focused mainly on the feasibility of detecting egg quality by an electronic nose combined with certain frequently used data analysis methods. However, limited detailed information is available on analyzing collected egg data by data preprocessing methods, as well as on tha comparison among the adopted chemometric methods. Therefore, combined with data preprocessing approaches and chemometric methods, this research aimed to study the feasibility of using electronic nose system to predict storage time and yolk index, which are both simple but representative indicators of egg quality.

2. Materials and methods

2.1. Sample preparation

All 160 eggs, bought at local supermarkets, were freshly laid and collected in Hongxing village, China. Once arrived in the laboratory, these eggs were cleaned and then stored in a chamber with condition of 20 °C and relative humidity of 70%. 20 eggs were used as spare samples in case of any broken ones, the other 140 eggs were divided into seven groups and each group contained 20 eggs that were numbered from 1 to 20. Each new group of eggs was analyzed weekly, the data-collecting experiment lasted for 6 weeks.

2.2. Electronic nose system and sample procedure

In this study, an Electronic nose (PEN2, Airsense Company, German) equipped with an array of metal oxide semiconductor (MOS) sensors was adopted to detect sample gas. The name and performance of each sensor are showed in Table 1. Sample gas is inhaled into the sensor channel from the air inlet by a built-in pump, then flows through the sensor array at a certain rate and finally is out from the outlet. The reference gas is the clean air filtered by activated carbon, and is inhaled at a certain rate by another pump, flows through and cleans the sensor array to make the responsive signal return to zero. Meanwhile, the reference gas also helps to prevent remnant gas from impacting the next process by cleaning the sensor array. The responsive signal is the ratio between the conductivity G when sensors get in touch with the sample gas and the conductivity G_0 when reference gas flows through the sensors (G/G_0).

Static head space sampling system was adopted for sensing volatile profile out of egg shell. Determined by a preliminary experiment, the mass of each egg was 60 ± 3 g and the most suitable sealing time was 1 h. The first step was to place each egg in a 500 mL beaker which was then sealed by preservative film for an hour and maintained at room temperature (25–27 °C). Then, the inlet tube was inserted into the beaker by using a syringe needle and the gas transmitted into the electronic nose. The electronic nose sampled and recorded data at the frequency of 1 Hz. Each sample was detected for 70 s. Finally, the detected eggs were broken to take out the complete yolk, and to measure the yolk index.

2.3. Measurement of yolk index

During storage, one significant change of egg is the decrease of vitelline membrane elasticity, allowing easier migration of water from the albumin through the weaker vitelline membrane (Jones & Musgrove, 2005). The result of this process is yolk flattening, which can be indicated by yolk index (*YI*). The procedure is: gently break an egg and pull apart the shell; then pour the egg liquid onto a big clean watch glass; finally measure the thickness and the diameter of yolk by using a vernier caliper. The *YI* was defined as follows (Funk, 1948):

$$YI = \frac{h}{d} \times 100\% \tag{1}$$

where h denotes the thickness of yolk, and d denotes the diameter of yolk.

According to Funk (1948), *YI* indicates the viscosity of yolk, and the higher *YI* is, the better egg quality is. In this research, *YI* for each egg group was determined by averaging the value of 20 egg samples each time.

Table 1
Electronic nose (PEN2), name and main performance of each sensor.

Number	Name	Main performance	Reference
S1	W1C	Aromatic compounds	Toluene, 10 mg/kg
S2	W5S	Very sensitive, broad range sensitivity, react on nitrogen oxides, sensitive with negative signal	NO_2, 1 mg/kg
S3	W3C	Ammonia, used as sensor for aromatic compounds	Benzene, 10 mg/kg
S4	W6S	Mainly hydrogen, selectively, (breath gases)	H_2, 100 mg/kg
S5	W5C	Alkenes, aromatic compounds, less polar compounds	Propane, 1 mg/kg
S6	W1S	Sensitive to methane (environment) ca. 10 mg kg^{-1}. Broad range, similar to S8	CH_3, 100 mg/kg
S7	W1W	Reacts on sulfur compounds, H_2S 0.1 mg kg^{-1}. Otherwise sensitive to many Terrenes and sulfur organic compounds, which are important for smell, limonene, praline	H_2S, 1 mg/kg
S8	W2S	Detects alcohol's, partially aromatic compounds, broad range	CO, 100 mg/kg
S9	W2W	Aromatic compounds, sulfur organic compounds	H_2S, 1 mg/kg
S10	W3S	Reacts on high concentrations >100 mg kg^{-1}, sometimes very selective (methane)	CH_3, $10CH_3$, 100 mg/kg