Electronic Nose for Detecting Strawberry Fruit Maturity

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ADDITIONAL INDEX WORDS. Fragaria × ananassa, principal components analysis, strawberry maturity, volatiles

An electronic nose (e-nose) composed of 18 different metal oxide gas sensors was used to characterize the volatile patterns of ‘Strawberry Festival’ and ‘Florida Radiance’ strawberry fruit at five developmental stages: white, half red, three-quarter red, full ripe, and overripe. Strawberry samples were harvested at three harvest dates from early February to the end of March. Three-gram aliquots of strawberry puree were employed for headspace sampling in 10-mL vials, which were incubated at 40 °C for 2 min prior to analysis. Volatiles from each sample were sampled for 2 min with data acquisition every second. After analysis, there was an 18-min delay for sensor recovery. E-nose sensor data was reproducible with 90% of sensor responses having relative standard deviations of less than 10%. Sensors P30/1, T30/1, and P30/2 were the major differentiating sensors for strawberry maturity as indicated by their loadings on the first principal component (PC1). Immature and less mature fruit were well separated from full ripe and overripe fruit on PC1, regardless of cultivar. Harvest date was separated primarily by the second principal component. E-nose volatile patterns of ‘Strawberry Festival’ and ‘Florida Radiance’ strawberry cultivars were separated at identical stages of development. E-nose technology has the potential to monitor strawberry maturity and fruit quality.

Most strawberries are consumed fresh, which requires that the fruit be pleasing in flavor, texture, and appearance. The fruit also needs to maintain good quality during and after long-distance transit. Strawberry is a non-climacteric fruit and, as such, has low CO2 and ethylene production after harvest. Primary ripening features include: texture softening, pigment synthesis, increasing volatile production and sugar content, and decreasing acidity. The maturity stage at which strawberries are harvested plays a key role in balancing these qualities. Commercially, fruit is often harvested slightly under-ripe, which will assure longer storage life through shipping and on market shelves compared to fully ripe fruit. These less mature berries are firmer, will maintain a shiny appearance for a longer period of time, and will likely show less decay. However, their overall flavor is usually poorer than that of fully ripe berries (Miszcza et al., 1995).

Therefore, monitoring quality changes of strawberry as a function of fruit maturity is important. Generally, total sugars (measured as soluble solids content), titratable acidity, and color are the major indices for fruity quality control. However, these indices cannot guarantee flavor quality. Strawberry taste and aroma are among the most important quality attributes that influence consumer consumption and repurchase decisions. For many years, gas chromatography (GC) and GC-mass spectrometry (GC-MS) have been used widely for the characterization of the aroma of fruit. However, these methods are costly, time-consuming, and limited to well-equipped laboratories. Rapid, nondestructive measurement techniques to determine fruit aroma in a consistent and reproducible manner would help determine the optimal picking maturity for a given variety and assist in quality control.

Electronic nose (e-nose) is a technique that employs an array of electronic gas sensors to detect and distinguish headspace volatiles via a pattern-recognition algorithm. An e-nose is composed of three parts, including a sample handling system, a detection system, and a data processing system. The detection system, namely the sensor array, is the “heart” of the e-nose. Generally, the sensor array consists of a cluster of broadly tuned sensors that are treated with a variety of odor-sensitive biological or chemical materials, which can generate slightly different responses to volatile mixtures to create a characteristic fingerprint for the mixture (Peris and Escuder-Gilabert, 2009). The gas sensors could be piezoelectric, electrochemical, optical, or calorimetric (Peris and Escuder-Gilabert, 2009). These sensors respond to the unseparated volatiles emanating from the fruit, which roughly mimics the human sense of smell. A database can be constructed from known sensor patterns or fingerprints, which is used to train a pattern recognition system so that unknown odors can subsequently be monitored and classified (Peris and Escuder-Gilabert, 2009). E-noses have been applied to the raw product quality control of fruit such as peach (Benedetti et al., 2008), apricots (Solís-Solís et al., 2007), mango (Lebrun et al., 2008), blueberry (Simon et al., 1996), and tomato (Berna et al., 2005). Limited studies have been investigated for the use of e-nose to detect strawberry aroma. Buratti et al. (2006) found a portable e-nose (PEN2) was able to reveal strawberry aroma changes during osmotic dehydration;
while another e-nose, Fox 3000, could discriminate strawberry varieties (Hirschfelder et al., 1998). E-nose has never been used for strawberry maturity monitoring.

In Florida, strawberry is the second most important fruit product. Florida is the principal supplier of fresh strawberries to the eastern and midwestern United States during December, January, and February (Jouquand et al., 2008). ‘Strawberry Festival’ is the dominant commercial strawberry cultivar in central Florida because of its excellent fruit quality and steady yields of medium-sized fruit throughout the season (Chandler et al., 2009). ‘Florida Radiance’ is a new strawberry cultivar that produces high yields of large, glossy fruit from December through March and has a yield pattern complementary to that of ‘Strawberry Festival’ (Chandler et al., 2009). The objective of this “proof of concept” study is to use e-nose to measure the volatiles of ‘Strawberry Festival’ and ‘Florida Radiance’ strawberries at five different fruit developmental stages: white, half red, three-quarter red, full ripe, and overripe.

Materials and Methods

Two strawberry cultivars, ‘Strawberry Festival’ and ‘Florida Radiance’, were grown at the Gulf Coast Research and Education Center, University of Florida, Wimauma, FL. Fruit were hand-harvested at five developmental stages including white, half red, three-quarter red, full red, and overripeness on three harvest dates (9 Feb., 25 Feb., and 8 Mar. 2010). Sorting of maturity stages was refined on a bench under natural day light upon arrival in the laboratory.

After harvest, strawberries were stored at 5 °C overnight, and transferred to room temperature for processing. Two hundred grams of fresh strawberry samples were pureed in a Waring blender (Waring Products Div., Dynamics Corp. of America, New Hartford, CO) at a high speed pulse mode for 20 s, with an equal weight of a solution of freshly distilled water, 20% sodium chloride, and 1% sodium fluoride (final concentration). Sodium chloride was employed to inhibit enzyme activity and sodium fluoride was used to inhibit polyphenol oxidase activity and microbial growth. Three-gram aliquots of puree were each sealed in separate 10-mL glass vials for triplicate sampling. Samples were then frozen and thawed prior to each electronic nose (e-nose) analysis.

The e-nose system employed was a FOX 4000 from Alpha M.O.S. (Toulouse, France). It consisted of 18 different metal oxide gas sensors (LY2/AA, LY2/G, LY2/gCT, Ly2/Gh, LY2/LG, P10/1, P10/2, P30/1, P30/2, P40/1, P40/2, PA2, T30/1, T40/1, T40/2, T70/2, T40/1, and TA2). The gas sensors were housed in three temperature-controlled chambers. A HS 100 autosampler (Alpha M.O.S.) was used for sampling volatiles. Air with a calcium chloride post-dehydration column was provided to the system. The flow rate was kept at 150 mL/min. The Alpha M.O.S. software, AlphaSoft® V12, was used for hardware monitoring, data recording and data processing. During analysis, strawberry samples in vials were incubated at 40 °C in a vessel for 2 min. One milliliter of headspace was introduced to the e-nose chamber using the autosampler. Each sample was then analyzed by e-nose for 2 min with data collected every second (total 120 data points). The maximum value for each sensor during the 120 second sampling period was used to plot data on a radar graph and for Principal Component Analysis (PCA). PCA was performed using the Unscrambler® software V10.0.1 (Camo Inc., Woodbridge, NJ). Following each analysis, the instrument was programmed for an 18-min sensor recovery.

Results and Discussion

In this study, 18 different metal oxide gas sensors were used to characterize strawberry fruit maturity stages. Figure 1 is an example of sensor values obtained from the 18 sensors for strawberry fruits at the white and overripeness stages. The 18 spokes of the “radar” chart represent the 18 individual responses in the sensor array. The responses from each of the 18 sensors during the 120 s sampling period is shown in Fig. 2 and maximum values for each sensor are recorded and employed for data analysis. In terms of pattern recognition software, each sensor value is considered as a discrete value as part of the set of 18 values which characterize each sample in the database. As seen in Figs. 1 and 2, different
sensors had different responses to strawberry volatiles. Even though some sensors responded more strongly than others, it is the response differences between samples which help to characterize strawberry odorants. Sensors P30/1, T30/1, and P30/2 provided some of the greatest and most differentiating responses for the volatiles from strawberries of different maturities (Fig. 1).

Three sets of data from both cultivars on three different harvest dates were collected. Shown in Fig. 3 are the principal component analysis (PCA) score plots of e-nose sensor responses to the headspace volatiles from the two strawberry cultivars at five levels of maturity harvested Feb. 9, Feb. 25 and Mar. 8, 2010. Ripeness increased from left to right on PC1. All three plots separated samples by maturity, with the least mature (white and half ref) on the left hand side and the full ripe and overripe on the far right hand side of the plots. PC1 accounted for more than 90% of the variance in all three cases. After examining the loading values for all three harvest dates, it was found that the PC1 axis was primarily defined by sensors P30/1, T30/1 and P30/2 on the positive side and sensors LY2/AA and LY2/G on the negative side.

It is worth noting in Fig. 1, that these sensors were also among the most discriminating sensors for strawberries of different maturity. This information is important as it demonstrates the potential to develop a simpler, smaller e-nose sensor array that would be more economical and hopefully portable.

The PCA score plots shown in Fig. 3 also show that clustering of the individual triplicate samples of the same maturity is indicative of good instrumental replication and analytical reliability. The e-nose detected volatile differences between ‘Strawberry Festival’ and ‘Florida Radiance’ strawberry cultivars at the identical stages of development on the same harvest date as indicated by the separation between clusters of the same maturity. As seen in Fig. 3, the separation between the two cultivars was mostly along PC2, even though it explains only 2% to 4% of the total variance. The greatest separation between the two cultivars was at the first harvest (9 Feb.) with diminished separation on subsequent harvest dates.

It should not be surprising that strawberry cultivars and maturities could be distinguished from their volatile patterns. Strawberry

![PCA score plots for three harvest dates](image-url)
is a non-climacteric fruit, and volatile compounds are synthesized during a rather brief ripening period. During this period, volatile compounds are produced under genetic control from plant constituents such as carbohydrates, lipids, protein, and carotenoids (Perez et al., 1992). It was reported that during maturation, the major strawberry volatiles such as furanones and esters increased significantly and maximum volatile production was observed in fully red fruits (Ménager et al., 2004). Therefore, later stages had higher e-nose responses and the separation between the two rippest samples was greater than between the three least ripe samples (Fig. 2). The results in Fig. 3 also indicate that strawberries harvested at the “commercial ripe” stage are not very different from white or half-white fruit in terms of volatile composition as determined by the e-nose used in this study, especially for ‘Strawberry Festival’.

Shown in Fig. 4 is the PCA score plot from a single cultivar (‘Florida Radiance’) at three harvest dates. It is well documented that fruit volatile profiles are affected by seasonal and environmental conditions (Forney, 2001). In strawberry, esters are the predominant volatiles, comprising 25% to 90% of the total volatiles in fresh ripe strawberry fruit (Forney et al., 2000). However, ester content was found to be highly affected by harvest date, based on the ester content of eight Florida strawberry cultivars and advanced selections (Jouquand et al., 2008). The data from the current study indicate that different amounts of volatiles were produced in ‘Florida Radiance’ at different harvest dates.

In conclusion, the e-nose could distinguish between the five maturity stages of strawberry. The best separation was observed for the most mature stages and the least separation was observed for the least mature stages. As shown in Fig. 3, it was possible to differentiate the two strawberry cultivars at the earliest harvest date, but differentiation became more difficult as the season progressed. Harvest date influenced observed e-nose patterns, suggesting quantitative volatile changes due to harvest date, but the overall separation of least mature to most mature remained (left to right) constant. The e-nose used in this study is a laboratory model and not suited for field work. However, the potential for using this technology with a hand-held unit using a smaller array of sensors identified in this study offer potential principals upon which to base such an instrument. The potential to determine maturity differences in strawberries of different genotypes, harvest dates, growing location, etc., is possible but unproven at this point. Therefore, the e-nose technique could become a useful tool to monitor the strawberry maturity and fruit quality. However, since e-nose does not identify the specific volatile compounds and cannot quantify individual strawberry volatiles, an instrumental analysis (e.g., GC-MS) of volatile compounds should be conducted to confirm and explain any e-nose results.

**Literature Cited**


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**Fig. 4.** PCA plot of maturity stages of ‘Florida Radiance’ strawberry discriminated by e-nose (Legend: 1–3: harvest dates on (•) 9 Feb., (◊) 25 Feb., and (▲) 8 Mar.; R = ‘Florida Radiance’; w = white; hr = half red; cr = commercial ripe; fr = full ripe; or = over ripe.


