Electronic nose pattern, sensory profile and flavor components of cold stored 'Spring Belle' peaches: influence of storage temperatures and fruit maturity assessed at harvest by time-resolved reflectance spectroscopy

M. Vanoli[1,2] , G. Bianchi[1], and A. Rizzolo[1]
[1]Consiglio per la Ricerca e Sperimentazione in Agricoltura – Unità di ricerca per i processi dell'industria agroalimentare (CRA-IAA), Milano, Italy

S. Lurie
Postharvest Science, Agricultural Research Organization, Bet Dagan, Israel

L. Spinelli
Istituto di Fotonica e Nanotecnologie – CNR, Milano, Italy

A. Torricelli[2]
[2]Politecnico di Milano, Dipartimento di Fisica, Milano, Italy

Keywords: sugar and acid composition, sensory quality, peaches, non-destructive method, cold storage

Abstract

This work aimed at studying the influence of non-destructively grading fruit at harvest by time-resolved reflectance spectroscopy (TRS) on E-nose pattern, sensory attributes and flavor components of peaches stored for 1 month at different temperatures. At harvest, 240 'Spring Belle' peaches were measured by TRS, ranked according to decreasing μ_a670 (increasing maturity) in three maturity classes (less, medium, more mature) and stored at 0°C and 4°C. After 2 and 4 weeks of storage, peaches were put at 20°C and less (LeM) and more (MoM) fruit were analyzed after 2 and 3 days of shelf life for firmness, expressible juice, E-nose pattern, sugar and organic acid composition and were submitted to sensory analyses. Data were analyzed by PCA and four functions were extracted explaining 75% of total variance. PC1 grouped total acids, citric acid, malic acid, sourness, mechanical and sensory firmness against Su/Ac ratio, expressible juice, juiciness and sweetness and discriminated fruit according maturity marking the highest scores for LeM fruit stored for 2 weeks at 0°C at d2 of shelf life. PC2 was mainly related to E-nose sensors, opposing W1C, W3C and W5C sensors to W2S, W1S, W5S, W2W, W1W, W3S and W6S ones and its scores decreased with increasing storage time and decreasing temperature. PC3 was positively related to glucose, fructose and sorbitol and negatively to W5S, sourness and W1Wand decreased with storage time but only at 0°C. PC4 was strongly linked to sucrose and total sugars. These results showed that sorting peaches at harvest in different maturity classes by using TRS resulted in fruit developing different mechanical, chemical and sensory characteristics after storage. Peaches classified as less mature at harvest showed higher firmness and acids content and lower sugars and were consequently judged more firm, sour, less sweet, juicy and aromatic than more mature ones. E-nose discriminated fruit mainly according to storage conditions rather than to maturity degree, even if W5S, W1W and W2W showed the highest responses in the most mature fruit, that is in fruit belonging to the more mature class stored at 4°C.

INTRODUCTION

Peach (*Prunus persica* L.) is one of the most appreciated fruits by consumers for its juicy texture, high nutrient content and pleasant flavor. During ripening, flesh softening occurs as well as chlorophyll loss, carotenoid and anthocyanin accumulation, and modification of sugar, acid, and volatile profiles. All these processes influenced appearance, texture, flavor and aroma of peach fruit. Type and concentration of individual sugars and acids are responsible for peach flavor while the emission of specific volatiles is closely related to aroma perception (Colaric et al., 2005; Ortiz et al., 2009). Sugar, organic acid and volatile compositions of peach and nectarines depend on cultivar, maturity stage, postharvest handling and storage conditions (Lavilla et al., 2002; Borsani et al, 2009; Wang et al., 2009; Cano-Salazar et al., 2012).

It is well-known that peach quality is strictly dependent on fruit maturity and that there is a large variation in maturity even within the same harvest date. Therefore there is a great interest in improving the assessment of peach maturity currently based on skin color, that is not suitable for highly colored varieties (Slaughter et al., 2013), or on the destructive measurement of firmness. Several authors have found good correlations between chlorophyll-related spectral indices non destructively measured by spectroscopic techniques and the maturity degree in peaches and nectarines (Vanoli and Buccheri, 2012). The absorption at 670 nm, near to the chlorophyll-*a* peak, is actually measured by time-resolved reflectance spectroscopy (TRS). The absorption coefficient measured at 670 nm (μ_a670) has been shown to be an effective maturity index for nectarines: it is related to fruit biological age and is synchronized with firmness decay as softening occurred earlier in fruit with low μ_a670 at harvest (more mature) and later in high μ_a670 fruit (less mature) (Tijskens et al., 2007; Eccher Zerbini et al., 2006). This has practical implications, allowing the selection of nectarines for different market destinations, as successfully applied by Eccher Zerbini et al. (2009) in an export trial from Italy to The Netherlands. By measuring μ_a670 at harvest it was also possible to select nectarines having different ethylene production rates at harvest, during shelf life and after cold storage along with distinctive sugar, acid and aroma compositions (Vanoli et al., 2010; Rizzolo et al., 2013).

The assessment of the ripening stage in peaches can also be carried out using electronic nose (E-nose) as well as the differentiation of peaches subjected to different storage conditions, discriminating chilling injured fruit from healthy ones (Di Natale et al., 2002; Benedetti et al., 2008; Infante et al., 2008; Rizzolo et al., 2013).

This work aimed at studying the influence of non-destructively grading fruit at harvest by TRS on E-nose pattern, sensory attributes and flavor components during shelf life of peaches stored for 1 month at different temperatures.

MATERIALS AND METHODS

The experiment was carried out on peaches ‘Spring Belle’, an early season, fast melting-flesh cultivar characterized by a juicy texture and good taste even if with high acidity (Di Vaio et al., 2009). Peaches were harvested on June 22, 2010 in a commercial orchard in Faenza (Italy) and 240 selected fruit were individually measured on two sides by TRS at 670 nm using a portable prototype built at Politecnico di Milano (Torricelli et al, 2008). The μ_a670 values were averaged per fruit; fruit were ranked on the basis of decreasing μ_a670 (increasing maturity) and were randomized into 8 samples (30-fruit each) all having 10 fruit of less (LeM), medium and more mature (MoM) TRS maturity classes in order to have in each sample the whole range of μ_a. Then fruit were stored at 0°C and 4°C for 2 and 4 weeks. At the end of each storage period, peaches were put at 20°C and LeM and MoM fruit were analyzed after 2 and 3 days of shelf life for firmness, expressible juice (as a mealiness index), E-nose pattern, sugar and organic acid

composition and were submitted to sensory analyses.
Flesh firmness (8 mm Ø plunger mounted on a Texture Analyzer TA.Xtplus, crosshead speed 3.33 mm/s) and expressible juice (measured on Ø 1cm plug of fruit flesh just below the peel according to Lill et al., 1988) were evaluated for each fruit near the TRS measurement points. Then, for each sample, peaches within each maturity class were divided into two subsamples of five fruit, and analyzed for volatile pattern by a commercial E-nose (PEN3 portable electronic nose) and for sugar (glucose, fructose, sucrose and sorbitol) and organic acid (quinic, malic and citric acids) compositions by HPLC according to Rizzolo et al. (2013). The PEN3 portable electronic nose (Win Muster Airsense Analytics Inc., Germany) consists of a sampling section, a detector unit containing the array of sensors, and pattern recognition software (Win Muster v.3.0) for data recording and elaboration. The sensor array is composed of 10 metal oxide semiconductor (MOS) type chemical sensors: W1C (aromatic), W5S (broadrange), W3C(aromatic), W6S (hydrogen), W5C (aromatic aliphatics), W1S (broad), W1W (sulfur organic), W2S (broad alcohol), W2W (sulfur chlorinate), and W3S (methane aliphatics).

The same fruit were also submitted to sensory analyses using a panel of ten short-term-trained judges. At each day of shelf life, one peeled slice/fruit/TRS maturity class/storage temperature, coded with three digit random numbers, was presented to each panelist. In order to have the same differences in maturity (μ_a670) among fruit for all the ten assessors, fruit presented to each panelist had the same rank position in the samples. At the beginning of each session, a slice of a fruit not included in the experimental plan was tasted to eliminate the first tasting effect. Drinking water was provided as a palate cleaner between samples. Each sample was evaluated for the intensity of the sensory attributes firm, juicy, sweet, sour and aromatic using 120 mm unstructured line scales with anchors at 12 mm from the extremes (low, high).

Data were submitted to multifactor ANOVA considering TRS maturity class, storage conditions and day of shelf life as factors, and means were compared by Tukey's test at $P \leq 0.05\%$ (SAS Institute Inc., Cary, NC, USA). E-nose pattern was analyzed by Principal Component Analysis (PCA). PCA was also used to study the relationship among E-nose pattern, sensory analysis, firmness, expressible juice and sugar and acid compositions in relation to TRS maturity class, storage conditions and shelf life (SAS Institute Inc., Cary, NC, USA). Prior to statistical analyses, the rating scores of each sensory attribute were standardized by panelist to mean equal to 50 and standard deviation equal to 21 in order to remove the variability due to panelists using different parts of the scale.

RESULTS and DISCUSSION

On average, μ_a670 at harvest was 0.202 ± 0.003 cm^{-1} (mean ± standard error), showing similar values to those previously found for this cultivar (Rizzolo et al., 2013). The μ_a670 values were significantly different for each TRS maturity class having LeM peaches μ_a670 of 0.256 ± 0.003 cm^{-1}; MeM 0.200 ± 0.001 cm^{-1} and MoM ones 0.150 ± 0.003 cm^{-1}, while no difference was found among the eight samples.

On average, firmness was lower in MoM fruit, in those stored for 4 weeks, at 4°C and after 3 days at 20°C (Fig. 1). Firmness was highest at d2 of shelf life in LeM peaches stored at 0°C for 2 weeks, showing 40% of fruit values higher than 43 N (unripe peach) and the remaining fruit firmness values of 22-43N typical of ready to buy fruit (Crisosto et al., 2006; Rizzolo et al. 2009). Prolonging storage time up to 4 weeks, these fruits softened to about 27N, but only 40% of fruit could be considered ready to eat, even still slightly firm (9-22N, Rizzolo et al., 2009). At d3 of shelf life, all these peaches became ready for consumption (Crisosto et al., 2006; Rizzolo et al., 2009). LeM fruit stored at 4°C for 2 weeks was already soft after 2 days of shelf life (11N) and after 3 days 75% of fruit softened under 4N. MoM were already soft at d2 showing slight changes up to d3; most of fruit stored at 4°C softened below 4N.

Expressible juice was higher in MoM fruit (73% *vs* 65% for LeM), in those stored at 4°C (72% *vs* 67% at 0°C) and increased with shelf life (68% for d2 *vs* 70% for d3), confirming that this cultivar did not develop woolliness with cold storage even at 4°C (Rizzolo et al., 2013).

'Spring Belle' peaches showed a good flavor due to a good sugar content (84 ± 1g/kg) coupled with a high acidity (14±0.3g/kg), in agreement with Rizzolo et al (2013). Sugar and acid compositions significantly changed with TRS maturity class, storage conditions and shelf life (Fig. 2). On average LeM fruit showed a higher content of malic and citric acids, total acids, sorbitol and a lower content of quinic acid, sucrose, fructose, total sugars than MoM ones as already found by Vanoli et al. (2010) in 'Ambra' nectarines at harvest and by Rizzolo et al. (2013) in 'Spring Belle' peaches. Also the ratio total sugars/total acids was significantly lower in LeM (5.5±0.1) than in MoM (7.0±021) peaches. Opposite trends were observed in peaches stored in ripening conditions (4 weeks, 4°C, d3), mainly for acid composition and Su/Ac ratio.

TRS maturity class affected also sensory attributes, being MoM perceived less firm and sour but more juicy, sweet and aromatic than LeM ones (Fig. 3 left). Also Vanoli et al. (2010) found this behavior in sensory characteristic with TRS maturity class, even if in two unstored nectarine cultivars, underlining that MoM fruit were also more appreciated by assessors. No changes in sensory scores were observed with storage temperature in MoM peaches, while LeM fruit stored 4°C were judged less firm but more juicy, sweet and aromatic than those stored at 0°C. Storage time and shelf life significantly influenced texture attributes, and peaches at d3 were also judged sweeter and less sour than those assessed at d2.

E-nose pattern was analyzed by PCA; two functions were extracted, explaining 83% of the total variance (Fig. 3 right). PC1 grouped the sensors WIC, W3C and W5C against the other ones, while PC2 opposed W6S and W3S sensors against W5S, W1W and W2W. The responses of the 10 MOS sensors significantly changed with storage conditions and TRS maturity class with many interactions among factors. On average, PC1 scores were higher in fruit stored for 2 weeks, at 4°C and in LeM fruit; PC2 scores were higher at 0°C in LeM fruit and lower at 4°C in MoM ones (Fig. 3, right). It was confirmed that sensors W1W, W3C, W5C, W5S, W1W and W2W were able to discriminate peaches stored in different temperatures and that sensors W5S, W1W and W2W can also distinguish peaches of different maturity degrees, as found by Rizzolo et al. (2013).

Principal Component Analysis (PCA) was also used to study the relationships among E-nose pattern, sensory analysis, firmness, expressible juice and sugar and acid compositions in relation to TRS maturity class, storage conditions and shelf life (Fig. 4 and 5). Four functions were extracted explaining 77% of the total variance.

PC1 (32%) grouped total acids, citric acid, malic acid, sourness, mechanical and sensory firmness against Su/Ac ratio, expressible juice, juiciness and sweetness. PC1 was mainly related to maturity ,marking the highest scores for LeM fruit stored for 2 weeks at 0°C at d2 of shelf life (Fig. 4 and 6).

PC2 (28%) was mainly related to E-nose sensors, opposing W1C,W3C and W5C sensors to W2S, W1S, W5S, W2W, W1W, W3S and W6S ones; PC2 scores decreased with increasing storage time and decreasing temperature, showing the lowest values in

LeM stored at 0°C at d2 of shelf life (Fig. 4 and 6).

PC3 (8%) was positively related to glucose, fructose and sorbitol and negatively to W5S, sourness and W1W; PC3 scores decreased with storage time but only at 0°C, showing the highest values in peaches stored for 2 weeks at 0°C (Fig. 5 and 6).

PC4 (8%) was strongly linked to sucrose and total sugars. In fruit stored for 2 weeks PC4 scores increased with increasing temperature and decreased with shelf life; in fruit stored for 4 weeks PC4 scores decreased with increasing temperature and showed higher scores for MoM (Fig. 5 and 6),

CONCLUSIONS

Our results showed that sorting peaches at harvest in different maturity classes by using TRS resulted in fruit developing different mechanical, chemical and sensory characteristics after storage. In fact peaches classified as less mature at harvest showed higher firmness and acids content, lower sugars and were consequently judged more firm, sour, less sweet, juicy and aromatic than more mature ones. Furthermore, peaches of the two maturity class behaved in a different way with storage temperature: LeM fruit stored at 0°C showed the worse sensory profile, as they were judged firmer, more sour and less juicy, sweet and aromatic, while LeM fruit stored at 4°C improved their sensory characteristic becoming soft, juicier, sweeter and aromatic; MoM stored at both temperatures showed good sensory characteristics, very similar to those of LeM fruit stored at 4°C. E-nose discriminated fruit mainly according to storage conditions rather than to maturity degree, even if W5S, W1W and W2W showed the highest responses in the most mature fruit, that is in fruit belonging to MoM class stored at 4°C.

AKNOWLEDGEMENTS

We are grateful to Grant Agreement 228334 Laserlab-Europe II (EU FP7–Infrastructures - 2008-1) for a fellowship to Susan Lurie

Literature cited

Benedetti, S., Buratti, S., Spinardi, A., Mannino, S. and Mignani, I. 2008. Electronic nose as a non-destructive tool to characterise peach cultivars and to monitor their ripening stage during shelf-life. Postharvest Biol. Technol. 47:181-188.

Borsani, J., Budde, C.O., Porrini, L., Lauxmann, M.A., Lombardo, V.A., Murray, R., Andreo, C.S., Drincovich, M.F. and Lara, M.V. 2009. Carbon metabolism of peach fruit after harvest: changes in enzymes involved in organic acid and sugar level modifications. J. Exp. Bot. 60:1823-1837.

Cano-Salazar, J., Echeverría,G., Crisosto, C.H. and Lopez, L. 2012. Cold-storage potential of four yellow-fleshed peach cultivars defined by their volatile compounds emissions, standard quality parameters, and consumer acceptance. J. Agric. Food Chem. 60:1266-1282.

Colaric, M., Veberic, R., Stampar, F.and Hudina, M. 2005. Evaluation of peach and nectarine fruit quality and correlations beween sensory and chemical attributes. J. Sci. Food Agric. 85 2611-2616.

Crisosto, C.H., Crisosto, G.M., Echeverria, G: and Puy, J. 2006. Segregation of peach and nectarine (Prunus persica (L.) Batsch) cultivars according to their organoleptic characteristics. Postharvest Biol. Technol. 39:10-18.

Di Natale, C., Zude-Sasse, M., Macagnano, A., Paolesse, R., Herold, B. and D'Amico, A. 2002. Outer product analysis of electronic nose and visible spectra: application to the measurement of peach fruit characteristics. Anal. Chim. Acta 459:107-117.

Di Vaio, C., Graziani, G., Marra, L., Cascone, A. and Ritieni, A. 2008. Antioxidant capacities, carotenoids and polyphenols evaluation of fresh and refrigerated peach and nectarine cultivars from Italy. Eur. Food Res. Technol. 227:1225-1231.

Eccher Zerbini, P., Vanoli, M., Grassi, M., Rizzolo, A., Fibiani, M., Cubeddu, R., Pifferi, A., Spinelli, L. and Torricelli, A. 2006. A model for the softening of nectarines based on sorting fruit at harvest by time-resolved reflectance spectroscopy. Postharvest Biol. Technol. 39:223-232.

Eccher Zerbini, P., Vanoli, M., Rizzolo, A., Jacob, S., Torricelli, A., Spinelli, L. and Schouten, R.E. 2009. Time-resolved Reflectance Spectroscopy as a management tool in the fruit supply chain: an export trial with nectarines. Biosyst. Eng. 102:360-363.

Infante, R., Farcuh, M. and Menenes, C. 2008. Monitoring the sensorial quality and aroma through an electronic nose in peaches during storage. J. Sci. Food Agric. 88:2073-2078.

Lavilla, T., Recasens, I., Lopez, M.L. and Puy, J. 2002. Multivariate analysis of maturity stages, including quality and aroma, in 'Royal Glory' peaches and ''Big Top' nectarines. J. Agric. Food Chem. 82:1842-1849.

Lill, R. E.and van der Mespel, G. J. 1988. A method for measuring the juice content of mealy nectarines. Sci. Hortic. 36:267–271.

Ortiz, A., Echeverría, G., Graell, J. and Lara, I. 2009. Overall quality of 'Rich Lady' peach fruit after air- or CA storage. The importance of volatile emission. LWT-Food Sci. Technol. 42:1520-1529.

Rizzolo, A., Bianchi, G., Vanoli, M., Lurie, S., Spinelli, L. and Torricelli, A. 2013. Electronic nose to detect volatile compound profile and quality changes in 'Spring Belle' peach (*Prunus persica* L.) during cold storage in relation to fruit optical properties measured by time-resolved reflectance spectroscopy. J. Agric. Food Chem. 61:1671-1685.

Rizzolo, A., Vanoli, M., Eccher Zerbini, P., Jacob, S., Torricelli, A., Spinelli, L., Schouten R.E. and Tijskens, L.M.M. 2009. Prediction ability of firmness decay models of nectarines based on the biological shift factor measured by time-resolved reflectance spectroscopy. Postharvest Biol. and Technol. 54:131-140.

Slaughter, D.C., Crisosto, C.H. and Tiwari, G. 2013. Nondestructive determination of flesh color in clingstone peaches. J. Food Eng. 116:920-925.

Tijskens, L.M.M.,; Eccher Zerbini, P., Shouten, R.E., Vanoli, M., Jacob, S., Grassi, M., Cubeddu, R., Spinelli, L. and Torricelli, A. 2007. Assessing harvest maturity in nectarines. Postharvest Biol. Technol. 45:204-213.

Torricelli, A., Spinelli, L., Contini, D., Vanoli, M., Rizzolo, A. and Eccher Zerbini, P. 2008. Time-resolved reflectance spectroscopy for non-destructive assessment of food quality. Sensing Instrum. Food Qual. Safety 2:82-89.

Vanoli, M. and Buccheri, M. 2012. Overview of the methods for assessing harvest maturity. Stewart Postharvest Review, 1 (4):1-11

Vanoli, M., Eccher Zerbini, P., Rizzolo, A., Spinelli, L. and Torricelli, A. 2010. Time-resolved reflectance spectroscopy for the non-destructive detection of inner attributes and defects of fruit. Acta Hort.(ISHS) 877:1379-1386.

Wang, Y., Yang, C., Li, S., Yang, L., Wang, Y., Zhao, J. and Jiang, Q. 2009. Volatile characteristics of 50 peaches and nectarines evaluated by HP-SPME with GC-MS. Food Chem. 116:356-364.

Figures

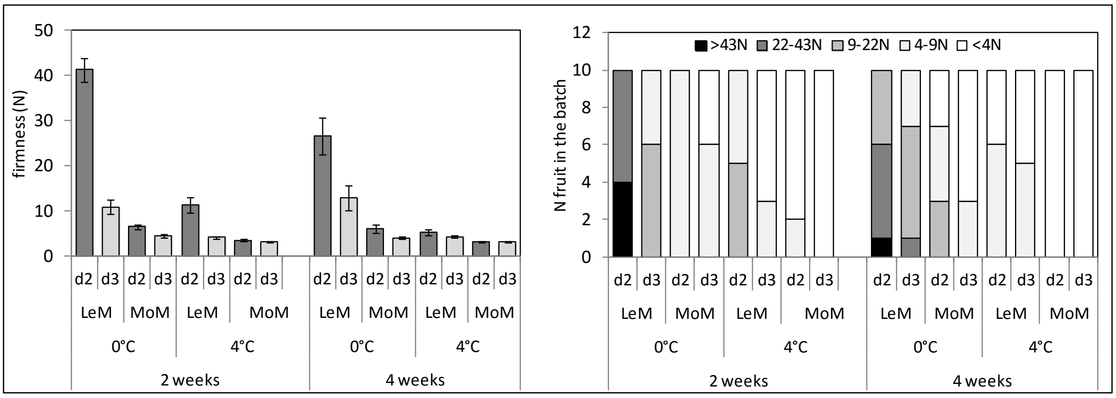

Fig. 1. Firmness of ‘Spring Belle’ peaches in relation to TRS maturity class, storage conditions and day of shelf life (left) and fruit distribution according to different class of firmness (right). Bars refer to standard error.

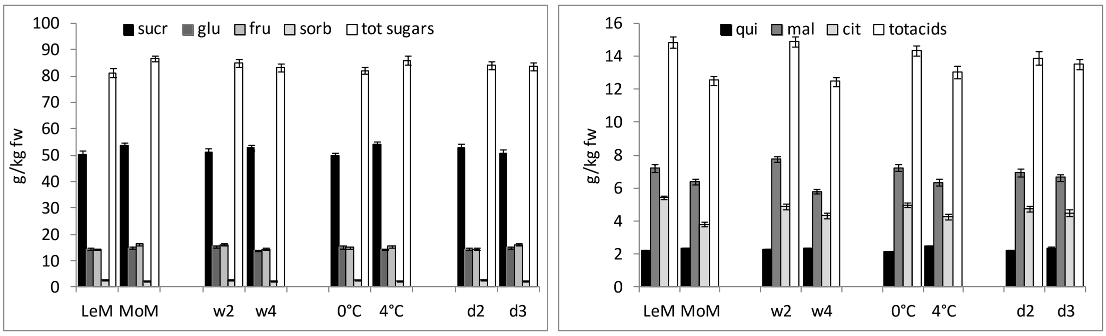

Fig. 2. Sugar (left) and acid (right) composition of ‘Spring Belle’ peaches in relation to TRS maturity class, storage conditions and day of shelf life. Bars refer to standard error

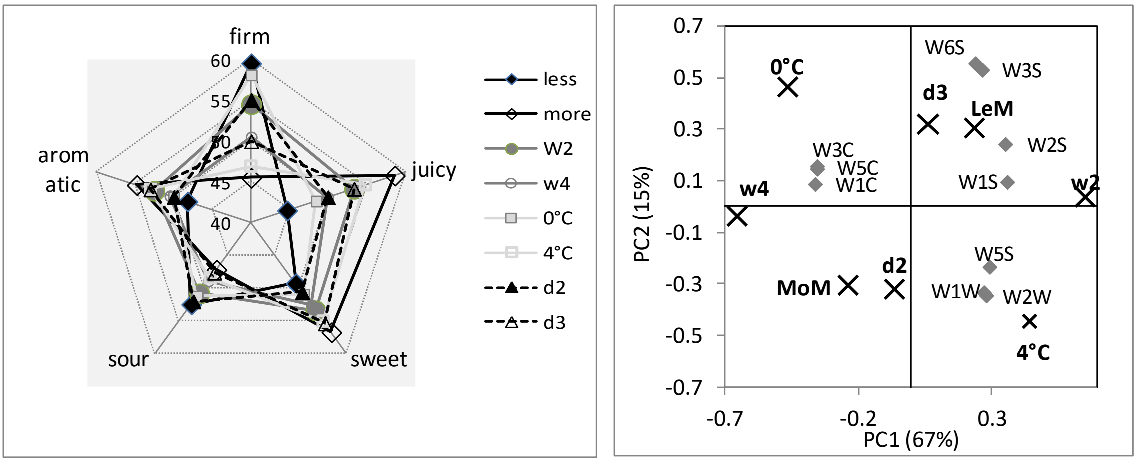

Fig. 3. Sensory attributes (left) and E-nose (right) pattern of ‘Spring Belle’ peaches in relation to TRS maturity class, storage conditions and day of shelf life.

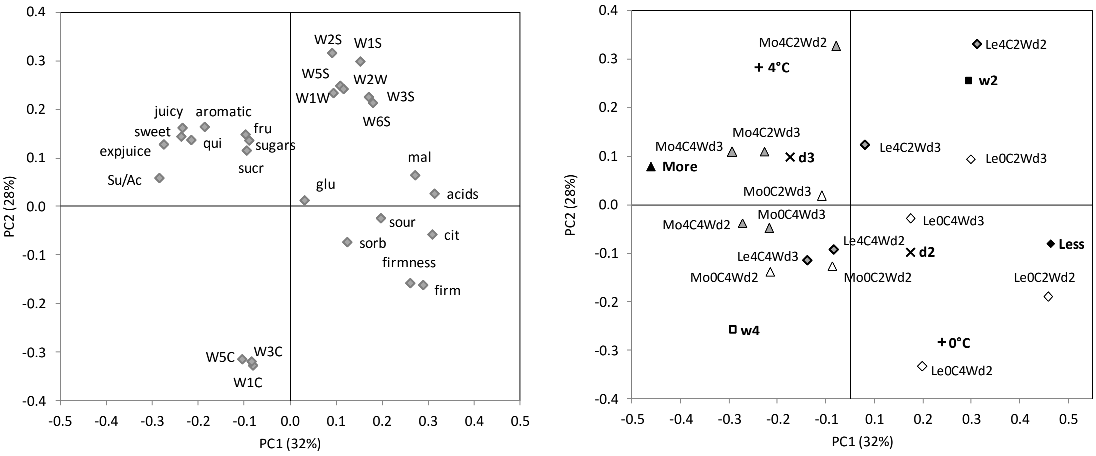

Fig. 4. Loadings (left) and scores (right) plots of PC1 versus PC2 from PCA on all variables (firmness, expressible juice, E-nose pattern, sensory attributes, sugar and acid compositions).

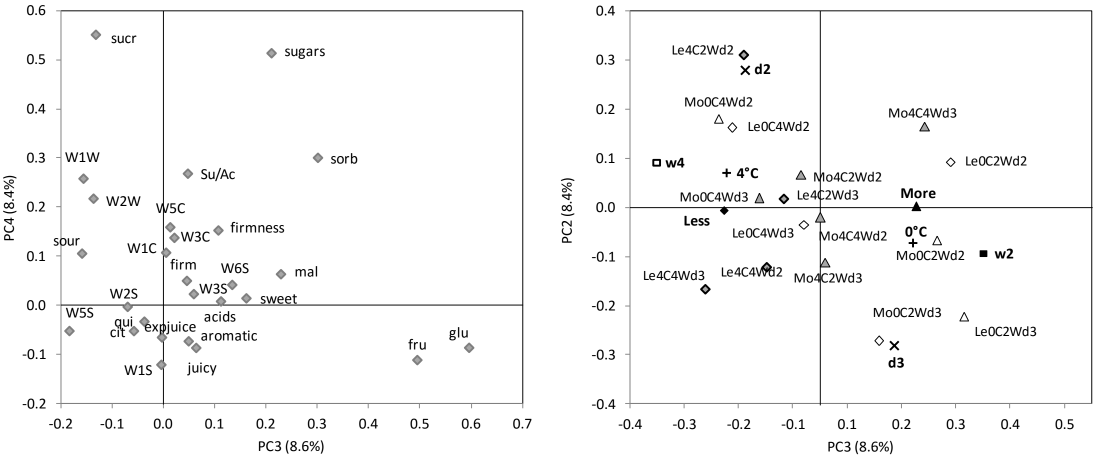

Fig. 5. Loadings (left) and scores (right) plots of PC3 versus PC4 from PCA on all variables (firmness, expressible juice, E-nose pattern, sensory attributes, sugar and acid compositions)

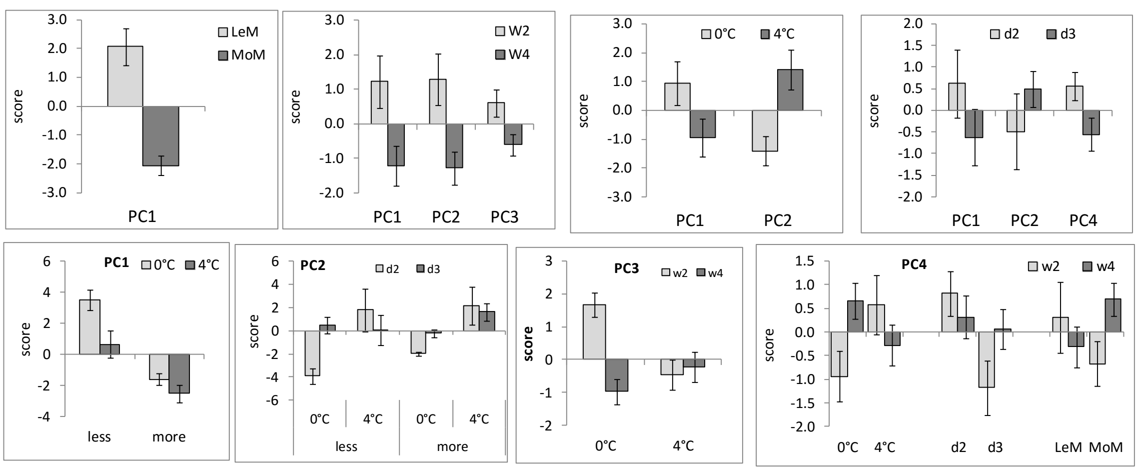

Fig. 6. Results of PCA: Principal Component (PC) scores in function of TRS maturity class, storage conditions and day of shelf life. Only significant effects are reported. Bars refer to standard error