Respiration Rate Changes in Fresh-Cut Peach Slices as Affected by Storage Time.

J. González-Buesa, A. Ferrer-Mairal, R. Oria and M.L. Salvador*
Vegetable Research Laboratory. University of Zaragoza. Miguel Servet 177, 50013 Zaragoza (Spain). E-mail: mlsalva@unizar.es

Keywords: Minimally processed, MAP, microperforation, modeling, IV gamme

Abstract

To design modified atmosphere packaging (MAP) suitable for minimally processed fruits it is necessary to know the respiration rate of the product. The respiration kinetics of fruits and vegetables is complex because of the large number of variables involved. Some variables such as the type of cultivar, degree of ripeness, storage temperature, and O_2 and CO_2 concentrations inside the package have been extensively studied. However, the effect of the length of time between harvest and processing still remains poorly known. The aim of this study was to determine the influence of the storage time prior to processing on the respiratory kinetics of fresh-cut peach slices and its application in modelling and designing packages with microperforated films. Peaches (*cv. Calante*) were harvested at commercial maturity stage and stored at 1 ºC and 95% RH for 21 days. Afterwards, whole fruit were washed, drained, peeled, stoned and cut into slices. The slices were dipped in a preserving solution at 2 ºC and then stored at 4 ºC in a humidified air flow. The respiration rate was determined at 0, 6, and 12 days in a closed system. Immediately after harvest, the respiratory rate of peach slices was also determined for use as a reference. The O_2 consumption and CO_2 production were measured by GC. The slices obtained from peaches processed immediately after harvest showed a higher respiratory rate than those stored for 21 days. The respiratory rate for the samples kept in air-flow diminished during the first 6 days. However, after 12 days the respiratory rate showed a sharp increase. A mathematical model was used to predict the evolution of the gaseous composition inside microperforated packages. The results show that for a proper MAP design, the changes in respiratory activity produced by storage time should be taken into account.

INTRODUCTION

Fresh-cut peach deteriorates faster than the whole fruit due to the wounding that occurs during processing (Cantwell and Suslow, 2002). Postharvest quality loss is primarily a function of respiration, onset or progression of ripening, water loss, enzymatic browning, microbial decay, senescence, and mechanical damage (Watada et al., 1996). Modified atmosphere packaging of minimally processed fruits and vegetables combined with cold storage are considered to be the best way to maintain sensory and microbiological quality of fresh-cut produce (Kader et al., 1989).

Modified atmosphere package design for minimally processed fruits is a complex task requiring understanding of the dynamic interactions established between the product, the atmosphere inside the package, and the package itself (Yam and Lee, 1995). Among the large number of variables to be integrated, such as the optimum gas composition, the

gas exchanges through the package, the free volume, and the weight of the product, the respiratory rate of the product is of great importance.

However, the respiration kinetics of fruits and vegetables is a complex matter, because of the large number of variables to be considered. In the case of peaches, some variables such as the type of cultivar, degree of ripeness, storage temperature, and O_2 and CO_2 concentrations inside the package have been extensively studied (Watada et al., 1996; Gorny et al., 1998). However, the effect of storage time still remains poorly known, even though for production management reasons peaches may go through a lengthy storage period at low temperature of many weeks before processing. Storage time after harvest may influence the respiratory rates due to the progress of ripening, physiological damage, microbiological growth, and senescence processes. Furthermore, changes in respiratory activity may have a significant influence on the atmosphere inside the packages of fresh-cut products and should be considered when designing packaging conditions. Mathematical models are useful tools for defining the characteristics that a package should have and for predicting the evolution of the gas composition during conservation of the product (Fishman et al., 1995; González-Buesa et al., 2009).

The aim of this study was to determine the influence of the storage time of already processed fruit on the respiratory kinetics of fresh-cut peach slices, and to gather information that could be used in designing modified atmosphere packaging systems.

MATERIAL AND METHODS

Fruit Material and Preparation of Fruit Slices

Peaches of the *Calante* variety were harvested at the commercial harvest point established for the cultivar in the region (SSC 11.4±0.9 ºBrix; acidity 6.1±1.0 g L^{-1} and firmness 3.6±0.4 kg cm^{-2}). After harvest, they were immediately transported to our laboratory, sorted to eliminate damaged or defective fruit, and stored for 21 days at 1 ºC and 95% RH. After storage, the whole fruit were washed in chilled water containing 100 ppm of sodium hypochlorite (adjusted to pH 6.5 with citric acid) for 5 min and then gravity drained. The peel was removed with an automatic peeler (Orange peeler, Pelamatic) and the fruit was pitted manually. Each fruit was cut into 10-12 slices with sharp stainless steel knives (Granton, U.K.). After peeling and slicing, the peach samples were dipped for 30 min in an aqueous solution at 2 ºC containing 20 g L^{-1} ascorbic acid, 10 g L^{-1} citric acid, and 10 g L^{-1} calcium chloride. The slices were then stored at 4 ºC in a humidified air flow of 250 mL min^{-1}. The respiratory rate was determined at 0, 6 and 12 days (named t21+0, t21+6 and t21+12, respectively). The respiratory rate of fruit slices immediately after harvest, processed as described above (t0+0 samples), was also determined for use as a reference. In the case of samples t0+0 and t21+0 measurements of respiratory activity were made 5 h after processing to avoid the effect of recently cut on the respiration rate.

Closed System Respiration Experiments

The measurement of respiratory activity was determined in a closed static system at 4ºC, as described by González-Buesa et al. (2009). Samples of 500 grams of peach slices were placed in hermetic containers (1230 mL capacity). The head space gas composition was regularly analyzed for O_2, CO_2, and N_2 by gas chromatography (Hewlett Packard 4890 equipped with a TCD). The initial atmosphere composition was that of air.

A Chrompack CP-Carboplot P7 column (inside diameter 0.53 mm, length 27.5 mm) was used with helium as the carrier gas at a flow rate of 12.6 mL min^{-1}. The initial temperature of the oven was set at 40 ºC and after 2.5 min this was increased at a rate of 45 ºC min^{-1} to a final temperature of 115 ºC. The temperature of the injector block was 59 ºC and the detector temperature was 120 ºC. The monitoring of the evolution of the gaseous composition in the interior of the containers was done in three different containers until the O_2 levels reached 1%. The results shown are average values of the three measurements taken.

Packaging

For the packaging experiments, t21+0 slices (500 g) were placed in polypropylene trays wrapped in polyethylene (700 mL capacity). The upper part of the package (96 cm^2) was heat sealed with two different microperforated films (Amcor P-Plus films, Amcor Flexibles, Ledbury, UK), which have a polymeric matrix made up of one layer of low density polyethylene and another of polyester. The films (40 µm thickness) differed in the transmission rate (two microperforations per tray of 90 x 50 µm and one microperforation per tray of 125 x 75 µm). The initial gas composition was similar to that of the atmosphere. Samples (5 trays) were kept in a cold room (4 ºC, 80 % RH) and the evolution of O_2 and CO_2 concentrations inside the packages was followed using GC. The gas composition was measured nine times during the storage period (210 h). The results shown are average values of the five replicates.

Mathematical Model

The mathematical model applied was that developed for microperforated packages whose volume remains constant as described in González-Buesa et al. (2009). It assumes that all flow through the package is produced only by means of the microperforations by ordinary diffusion. The diffusive flow obeys Fick´s law with a modification. The path length is the sum of the thickness of the film and a correction term equal to the radius of the microperforation (Fishman et al., 1995). A 4^{th}–order Runge-Kutta method was used to solve the differential equations that describe the variation with time of the amount of O_2 and CO_2 inside the packages. The mathematical model was solved for the two packages described above and for the respiration kinetics of the different samples (t0+0, t21+0, t21+6 and t21+12).

RESULTS AND DISCUSSION

The respiratory kinetics were determined from the results obtained in the closed system experiments. The O_2 and CO_2 concentrations inside the sealed packages containing peach slices changed with time in the expected pattern (Fig. 1). The O_2 concentration inside the flasks was higher for the peaches stored for 21 days and measured immediately after processing (t21+0) than for those processed immediately after harvest (t0+0). Although these differences are small, they are statistically significant ($p<0.05$).

The time elapsed after cutting had an influence on the respiratory activity. Six days after cutting (t21+6), the O_2 depletion and the CO_2 accumulation were lower than t21+0 data; however, after 12 days (t21+12), the peach slices showed higher rates of O_2 consumption and CO_2 production. The same tendency has already been described by several authors, both for whole fruit (Woodhard and Topping, 1972; El-Kazzaz et al., 1983) and for minimally processed fruits (Aquino-Bolaños et al., 2000; Gorny et al.,

2000; Rivera-López et al., 2005). The causes for this behavior of the respiratory activity can be found in the high metabolism of the peach tissues due to the cutting stress, and probable microorganism proliferation.

The temporal evolution of the O_2 and CO_2 concentrations within the closed system containers was fitted using the following equations:

$$O_2 = a \cdot e^{-b \cdot t} \quad (1)$$

$$CO_2 = c \cdot (1 - e^{-d \cdot t}) \quad (2)$$

where the O_2 and CO_2 concentrations are expressed in percentages and time (t) in h. The values of the fitting parameters *a*, *b*, *c* and *d* are shown in Table 1 with coefficients of determination (r^2) > 0.975.

The derivatives of Eq. (1) and (2) were used to obtain the experimental respiration rates for each product:

$$R_{O2} = -\frac{1}{W}\frac{V}{100}\frac{dO_2}{dt} \quad (3)$$

$$R_{CO2} = \frac{1}{W}\frac{V}{100}\frac{dCO_2}{dt} \quad (4)$$

where R_{O2} and R_{CO2} (mL kg^{-1} h^{-1}) are the respiration rate expressed as consumption of O_2 or production of CO_2, W (kg) is the product mass and V (mL) the free container volume. These respiration rates showed an exponential dependence with time and a linear relation with the O_2 concentration (Fig. 2). In air, the respiration rate of slices t21+12 (expressed as O_2 consumption) was 2 times greater than that of the samples t21+6. Nevertheless, this difference diminished as the O_2 concentration declined. Initially, the just harvested and processed samples (t0+0) showed a higher respiration rate than those stored and processed after 0 and 6 days (t21+0 and t21+6), respectively. This tendency was reversed for O_2 concentrations lower than 8%. In the t0+0, t21+0, and t21+6 samples there was a reduced dependence of the O_2 concentration on the CO_2 production rate. For the t21+12 samples, the R_{CO2} showed an O_2 concentration dependency similar to that of R_{O2}. The time from harvest affects the respiratory quotient in air (0.55 for t0+0 slices and 0.81 for t21+0 samples). At lower O_2 concentration, both respiratory quotients were nearing up to a value close 1.

The mathematical model was solved for the above determined respiratory kinetics and for the two packages (with one hole of 125 x 75 μm and with two holes of 90 x 50 μm). The concentration of O_2 predicted by the model is shown in Fig. 3, as well as the experimental data. Initially, the empirical results show a logical drop in the O_2 concentration with time up to a value that depends on the film transmission rate. However, once the lowest value is reached, instead of stabilizing at a stationary value as expected, it increases at 100-120 h in both cases.

In order to explain this fact, a hypothesis was proposed that the respiration rate of the product would change during its shelf-life. Regarding the results provided by the mathematical model, it can be observed that when this is run considering the respiratory activity of t0+0 samples (continuous line in Fig. 3), the predictions agree with the experimental data up to a point at which the O_2 concentration increases. The simulations of packaging also show that the cold storage of the whole fruit for 21 days prior to processing (t21+0, dash line in Fig. 3) does not involve changes in metabolism significant enough to have an effect on the evolution of the gas composition inside the packages.

On the other hand, if the equations describing the respiration of t21+6 slices are considered (dotted line in Fig. 3), higher concentrations of O_2 are found than in the t0+0 case for both films. Furthermore, these are very close to the experimental data for times longer than 120 h. This indicates that for an appropriate design of the container, the change in the respiratory activity during storage time should be taken into account. Respiration rate changes according to gas concentration within packages but also due to the tissue metabolism. The results obtained in a previous work (González et al., 2008) seem to point towards the microbial proliferation is not the reason of the respiration rate changes. If the respiration rates of the t21+12 samples are used, the model indicates that a lower O_2 concentration is obtained than in the other cases (dash-dot line in Fig. 3). According to these results, if experimental data were available we would expect, for storage times of longer than 288 h (12 days), that the O_2 concentration would decrease markedly, probably due to microbiological growth and senescence phenomena.

Acknowledgements

The authors express their gratitude to the INIA "Plan Específico para Teruel" (Project PET 2007-009-C05-03) and to the 'Diputación General de Aragón' for providing the financial support for this study.

Literature cited

Aquino-Bolaños, E.N., Cantwell, M.I., Peiser G. and Mercado-Silva, E. 2000. Changes in the quality of fresh-cut jicama in relation to storage temperatures and controlled atmospheres. J. Food Sci. 65: 1238-1243.

Cantwell, M. and Suslow, T. 2002. Postharvest handling systems: fresh-cut fruits and vegetables. Postharvest Technology of Horticultural Crops. Publication 3311. Agricultural and Resources. University of California.

El-Kazzaz, M.K., Sommer, N.F. and Fortlage, R.J. 1983. Effect of different atmospheres on postharvest decay and quality of fresh strawberries. Phytopatology 73: 282-285.

Fishman, S., Rodov, V., Peretz, J. and Ben-Yehoshua, S. 1995. Model for exchange dynamics in modified atmosphere packages of fruits and vegetables. J. Food Sci. 60: 1078-1083.

González, J., Arias, E., Salvador, M.L. and Oria, R. 2008. Modeling of changes in atmosphere composition in fresh-cut peach packages due to temperature fluctuations. Food Sci. Tech. Int. 14 (Suppl. 5) : 109-116.

González-Buesa, J., Ferrer-Mairal, A., Oria, R. and Salvador, M.L. 2009. A mathematical model for packaging with microperforated films of fresh-cut fruits and vegetables. J. Food Eng. 95: 158-165.

Gorny, J.R., Hess-Pierce, B. and Kader, A.A. 1998. Effects of fruit ripeness and storage temperature on the deterioration rate of fresh-cut peach and nectarine slices. HortScience 33 (1) :110-113.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B. and Kader A.A. 2000. Quality changes in fresh cut pear slices as affected by cultivar, ripeness, stage, fruit size and storage regime. J. Food Sci. 65: 541-544.

Kader, A.A., Zagory, D. and Kerbel, E.L. 1989. Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. 28: 1-30.

Rivera-López, J., Vázquez-Ortiz, F.A., Ayala-Zavala, J.F., Sotelo-Mundo, R.R. and González-Aguilar, G.A. 2005. Cutting shape and storage temperature effect overall quality of fresh-cut papaya cv. *Maradol*. J. Food Sci. 70: S482-S489.

Watada, A.E., Ko, N.P. and Minott, D.A. 1996. Factors affecting quality of fresh-cut horticultural products. Postharvest Biol Tec. 15: 201-205.

Woodward, J.R. and Topping, A.J. 1972. The influence of controlled atmosphere on the respiration rates and storage behaviour of strawberry fruits. J Hort. Sci. 47: 547-553.

Yam, K.L. and Lee, D.S. 1995. Design of modified atmosphere packaging for fresh produce. In M.L. Rooney (ed.), Active Food Packaging. Chapman&Hall, Glasgow.

Tables

Table 1 Parameters a, b, c and d (Equations 1 and 2) describing the time evolution of O_2 and CO_2 concentrations for peach slices.

Conditions	a	b	r^2	c	d	r^2
t0+0	21.664± 0.342	0.0334 ± 0.0011	0.989	101.365 ± 38.227	0.00304 ± 0.00126	0.993
t21+0	22.255 ± 0.484	0.0310 ± 0.0013	0.977	51.137 ± 3.535	0.00761± 0.00065	0.999
t21+6	22.457 ± 0.466	0.0272± 0.0098	0.975	193.742 ± 82.176	0.00126± 0.00055	0.999
t21+12	21.658 ± 0.554	0.0491 ± 0.0024	0.977	29.657 ± 1.631	0.0226 ± 0.002	0.997

Figures

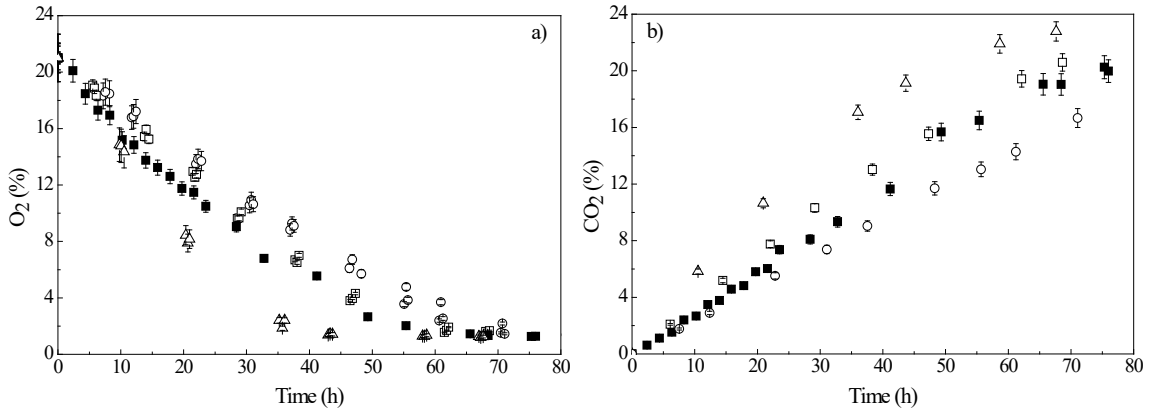

Fig.1 Time course of O_2 depletion (a) and CO_2 accumulation (b) in the closed container atmosphere containing peach slices of different conditions: ■ t0+0, □ t21+0, ○ t21+6, Δ t21+12. Data are average values of three replicates. Bars represent standard deviation.

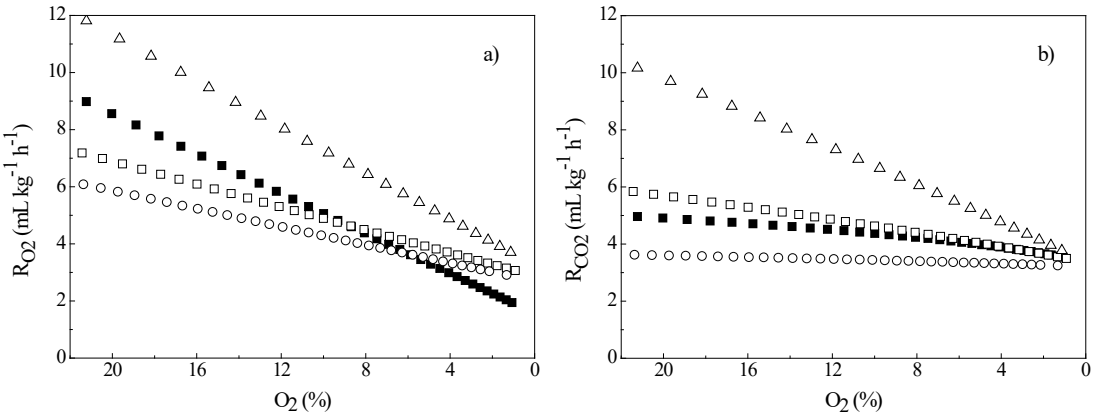

Fig. 2 Respiration rate expressed as O_2 consumption (a) and as CO_2 production (b) of different samples: ■ t0+0, □ t21+0, ○ t21+6, Δ t21+12.

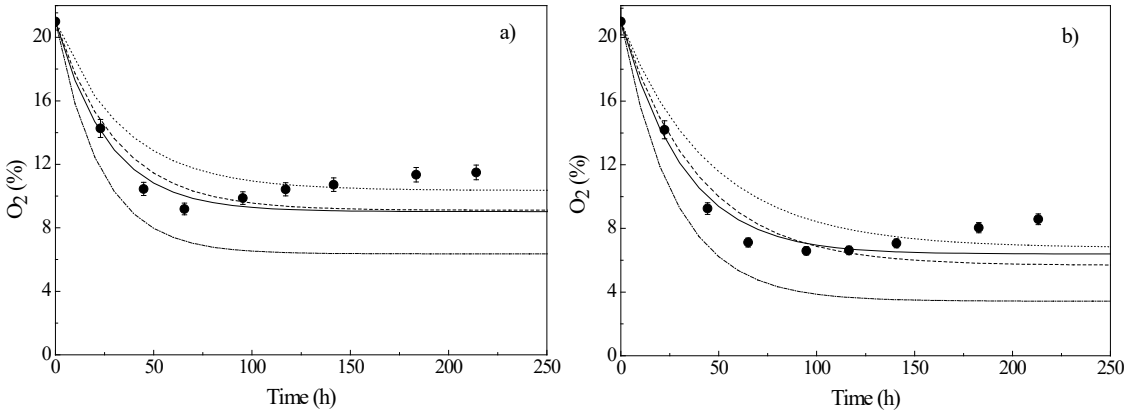

Fig. 3 Experimental (●) and predicted evolution of O_2 composition for different respiration rates (t0+0, continuous line; t21+0, dash line; t21+6, dot line; t21+12, dash dot line) and packages: (a) one 125x75 µm hole, (b) two 90x50 µm holes. Each experimental point is a mean value of five replicates. Bars represent standard deviation.