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# Physiological responses and quality attributes of peaches kept in low oxygen atmospheres

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ABSTRACT

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Peach (*Prunus persica* L., cultivar 'Fairtime') fruits were kept in air and in 0.25 or 0.02% $O_2$ at 0 or 5 °C for up to 40 days to study the effects of temperature and insecticidal low $O_2$ atmospheres on their physiological responses and quality attributes. Exposure to low $O_2$ atmospheres for 3 days reduced respiration and ethylene production rates and internal $CO_2$ concentration, but slightly increased resistance to $CO_2$ diffusion. The low $O_2$ treatments delayed incidence and reduced severity of internal breakdown (chilling injury) and decay of the peaches stored at 5 °C. Low $O_2$ atmospheres did not significantly influence changes in skin color, flesh firmness, and soluble solids content, but retarded titratable acidity loss and pH rise. Ethanol and acetaldehyde accumulated in peaches kept in 0.02% $O_2$ at 0 or 5 °C or in 0.25 $O_2$ at 5 °C. The fruits kept in air or 0.25% $O_2$ at 0 °C for up to 40 days and those stored in 0.02% $O_2$ at 0 °C or in air, 0.25 or 0.02% $O_2$ at 5 °C for up to 14 days had good to excellent taste, but the flavor of the fruits stored at 5 °C for more than 29 days was unacceptable.

## INTRODUCTION

There is increasing interest in studying the potential of short-term exposure to controlled atmospheres (CA) with $O_2$ levels below 1% and/or $CO_2$ levels about 50% for postharvest insect disinfestation to meet quarantine requirements of fresh fruits and vegetables (Aharoni et al., 1979; Benshoter, 1987; Lidster et al., 1981, 1984; Soderstrom et al., 1990). Controlled atmosphere treatments can be used for quarantine procedures only when they can effectively kill the insects of concern without detrimental effects on the host commodities.

Treatments with 1–5% $O_2$ and/or $CO_2$ were reported to retard softening and color development, reduce respiration and ethylene production rates, and reduce internal breakdown and decay of peaches and nectarines (Anderson

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and Penny, 1975; Smith and Anderson, 1975; Wade, 1981; Anderson, 1982; Wang and Anderson, 1982; Kader et al., 1982; Smilanick and Fouse, 1989). Storage of peaches and nectarines in 1% $O_2$+5% $CO_2$ with intermittent warming reduced internal breakdown, extended storage life, and maintained high contents of sugars and acids and a high degree of unsaturated of fatty acids (Wang and Anderson, 1982). However, if stone fruits were exposed to stress levels of low $O_2$ and/or high $CO_2$ atmospheres for a period longer than the time they could tolerate, detrimental effects such as abnormal ripening, flesh browning, and large increases in ethanol and acetaldehyde contents sometimes occurred (Kader, 1986; Smilanick and Fouse, 1989).

The purpose of this research was to study the effects of 0.25 and 0.02% $O_2$ at 0 or 5°C on physiological responses and quality attributes of peaches, in order to determine their tolerance to low $O_2$ atmospheres and the potential of using such CA treatments as quarantine procedures for postharvest insect disinfestation.

## MATERIALS AND METHODS

*Materials and treatments.* — Fruits of peach cultivar 'Fairtime' were obtained on the day of harvest from a commercial shipper in Fresno County, CA, and transported in an air-conditioned car to our laboratory at Davis where they were kept overnight at 0°C. The experiments were initiated the next morning. Six defect-free fruits were put into a 4 l glass jar as one replicate with three replicates used per treatment. In one experiment, the fruit samples were kept under a continuous flow of air, 0.25% $O_2$, or 0.02% $O_2$ (balance was $N_2$) at 0 or 5°C for 3 days before they were measured for respiration, ethylene production, internal $CO_2$ concentration, and resistance to gas diffusion. In another experiment, the fruit samples were kept in the above-mentioned atmospheres at 0 or 5°C for 7, 14, 29 or 40 days, and then transferred to air at 0°C for 7 days to allow ethanol and acetaldehyde contents to decrease, which was followed by transfer to air at 20°C for 3 days to allow the fruits to ripen before final quality evaluations.

*Gas analysis.* — The required $O_2$ and $CO_2$ concentrations of all gas mixtures were verified by analysis of a 10 ml gas sample using an $O_2$ analyzer (Model S-3AII, Applied Electrochemistry, Sunnyvale, CA) in series with an infrared $CO_2$ analyzer (Model PIR-2000, Horiba Instrument, Irvine, CA). Respiration rate was estimated by measuring the $CO_2$ concentration from the headspace of the jar holding the fruits, the flow rate used, and the fresh weight of the sample. The vacuum extraction method of Saltveit (1982), as modified by Ke and Kader (1990), was used to determine internal $CO_2$ concentration and resistance to gas diffusion. Resistance to $CO_2$ diffusion was calculated by the ratio: $([CO_2]_{Int} - [CO_2]_{Ext})/CO_2$ production rate.

Ethylene production rate was estimated by measuring the ethylene concentration of the gas sample from each jar using a Carle gas chromatograph (Model 211) equipped with a flame ionization detector.

*Determination of quality attributes.* — Three initial samples of six fruits each were evaluated for external and internal appearances, skin color, flesh firmness, soluble solids content, pH and titratable acidity, ethanol and acetaldehyde concentrations and flavor score. Similar measurements were done as part of the final quality evaluations. Appearance was scored using a subjective scale of 1 to 5 where 5 is excellent, 4 is good, 3 is fair, 2 indicates slight defects, and 1 indicates severe defects. Skin color was measured with a color difference meter (CDM) as "a" value, in which a larger positive number indicates a redder color. Flesh firmness was measured as penetration force with a UC fruit firmness tester, using an 8 mm plunger tip. Fruit juice was extracted with a hand press juicer, using four flesh sections from each fruit. Soluble solids content of the juice was measured with an Abbe refractometer and pH and titratable acidity were measured using an automatic titrator with a PHM85 Precision pH meter, an AUB80 autoburette, a PRS12 Alpha printer, and a SAC80 sample changer.

*Determination of ethanol and acetaldehyde contents.* — Ethanol and acetaldehyde concentrations in the fruit juice were measured by the method of Davis and Chace (1969) with some modifications. Frozen juice was thawed and a 5 ml sample was put in a 10 ml screw-cap test tube. The test tube was closed with a plastic cap and incubated in a water bath at 60°C. After 60 min, a headspace sample was taken with a 1 ml glass syringe for measurement of ethanol and acetaldehyde concentrations using an HP5890A gas chromatograph equipped with a flame ionization detector (at 250°C) and a glass column (2 mm × 1.0 m) containing 5% Carbowax on 60/80 Carbopack as a stationary phase (at 85°C).

*Estimation of internal breakdown.* — Internal breakdown (chilling injury) was visually estimated using a pretransformed scale of 1 to 5 according to the percentage of brown area of the fruit's longitudinal section: 1 indicating no injury; 2 indicating slight injury, 1–15% browning; 3 indicating moderate injury, 16–50% browning; 4 indicating severe injury, 51–85% browning; 5 indicating extreme injury, 86–100% browning.

*Estimation of decay severity.* — Decay was estimated using a pretransformed scale of 1 to 5 according to the percentage of affected surface area: 1 indicating no decay; 2 indicating slight decay, 1–15% area affected; 3 indicating moderate decay, 16–50% area affected; 4 indicating severe decay, 51–85% area affected; 5 indicating extreme decay, 86–100% area affected.

*Estimation of flavor score.* — Flavor was evaluated by tasting, using a scale of 1 to 7 where 7 is excellent, 6 is good, 5 is fair, 4 is slight off-flavor, 3 is moderate off-flavor, 2 is severe off-flavor, and 1 is extreme off-flavor. Three fruits were evaluated in each treatment with one section tasted in each fruit. The evaluation was done in the Postharvest Laboratory of the Pomology Department. The judge rinsed his mouth with drinking water between tastings to clean it of residual samples and to avoid the influence of flavors of fruits already tested. In previous studies with strawberries and oranges (Ke and Kader, 1990; Ke et al., 1991) we obtained more reproducible evaluation of the flavor of stored fruits using trained tasters ($n=4$), than with large untrained panels ($n>100$). In the present study, therefore, flavor was evaluated, following standard protocol, by one experienced taste panelist.

*Statistical analysis.* — Data were treated for multiple comparisons by analysis of variance with least significant difference (LSD) between means determined at the 5% level.

## RESULTS AND DISCUSSION

Exposure of 'Fairtime' peaches to 0.25 or 0.02% $O_2$ for 3 days generally reduced respiration rate and internal $CO_2$ concentration but increased resistance to $CO_2$ diffusion (Table 1). While $CO_2$ production rate and internal $CO_2$ concentration were generally higher at 5°C than at 0°C, resistance to

TABLE 1

Effects of storage temperature and $O_2$ level on respiration rate, internal $CO_2$ concentration, resistance to $CO_2$ diffusion ($r_{CO_2}$), and ethylene production rate of 'Fairtime' peaches after 3 days of storage in air, 0.25 or 0.02% $O_2$ at 0 or 5°C

| Temperature (°C) | Atmospheric composition | $CO_2$ production rate (ml $h^{-1}$ $kg^{-1}$) | Internal $CO_2$ (%) | $r_{CO_2}$ (% ml$^{-1}$ h kg) | $C_2H_4$ production rate ($\mu$l $h^{-1}$ $kg^{-1}$) |
|---|---|---|---|---|---|
| 0 | Air | 2.5 | 0.48 | 0.14 | 2.3 |
| | 0.25% $O_2$ | 1.4 | 0.40 | 0.24 | 0.1 |
| | 0.02% $O_2$ | 1.5 | 0.38 | 0.20 | 0.1 |
| LSD at 5% | | 0.4 | 0.04 | 0.07 | 0.2 |
| 5 | Air | 4.6 | 0.62 | 0.09 | 3.3 |
| | 0.25% $O_2$ | 2.4 | 0.43 | 0.14 | 0.2 |
| | 0.02% $O_2$ | 3.6 | 0.57 | 0.11 | 0.2 |
| LSD at 5% | | 0.8 | 0.10 | 0.02 | 0.2 |

$CO_2$ diffusion was lower at the higher temperature. The low $O_2$ treatments reduced ethylene production rates by more than 90%. The reduction in respiration and ethylene production rates are beneficial in retarding ripening of the fruits.

The peaches were partly red and yellow when harvested and the low $O_2$ treatments did not significantly influence the changes in either skin color (as indicated by CDM "a" value) or flesh firmness during the storage and ripening period (data not shown). When the peaches were stored at 0°C for up to 40 days, internal breakdown and decay were negligible in all atmospheres (Fig. 1A and 1C). When the fruits were stored at 5°C, however, internal breakdown and decay occurred after 14–40 days (Figs. 1B and 1D). The low $O_2$ treatments retarded or reduced the occurrence and severity of internal breakdown and decay and, therefore, alleviated these detrimental effects on the fruits. Wang and Anderson (1982) reported that 1% $O_2$+5% $CO_2$ with intermittent warming reduced internal breakdown of peaches and nectarines. Internal breakdown is one of the most important limiting factors in the storage of stone fruits. The occurrence of decay in peaches was probably due to the reduction in resistance to pathogen attack because of fruit deterioration.

When peaches were stored at 0°C, both external and internal appearances were good to excellent in all atmospheres for 7–40 days (Table 2). External and internal appearances of the fruits stored in air at 5°C decreased after 14 days and became unacceptable after 29 days. Exposure of the fruits to 0.25 or

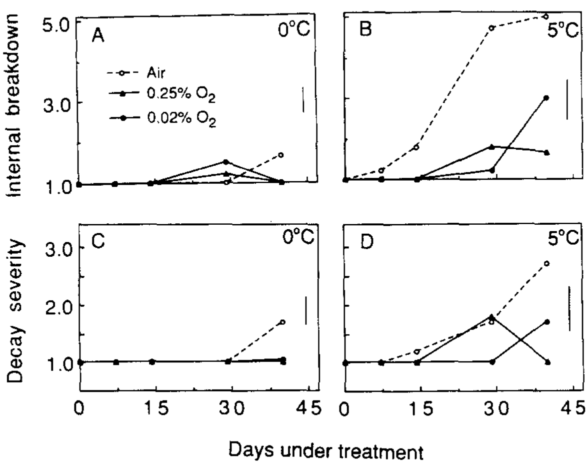


Fig. 1. Effects of storage temperature and $O_2$ level on internal breakdown and decay of 'Fairtime' peaches. The fruits were kept in air and in 0.25 or 0.02% $O_2$ at 0 or 5°C for 7, 14, 29, or 40 days followed by transfer to air at 0°C for 7 days and then to air at 20°C for 3 days. Severities of internal breakdown and decay were visually estimated using a pretransformed scale of 1 to 5 according to the percentage of brown area in the fruit's longitudinal section and affected surface area (see text for details). The vertical bars represent LSD values at $P=0.05$.

TABLE 2

Effects of storage temperature and $O_2$ level on appearance and flavor of 'Fairtime' peaches. The fruits were stored in air, 0.25 or 0.02% $O_2$ at 0 or 5 °C for 7, 14, 29, or 40 days followed by transfer to air at 0 °C for 7 days and then to air at 20 °C for 3 days

| Temperature (°C) | Atmospheric composition | External appearance[1] | | | | Internal appearance[1] | | | | Flavor[2] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7[3] | 14 | 29 | 40 | 7 | 14 | 29 | 40 | 7 | 14 | 29 | 40 |
| 0 | Air | 4.8 | 5.0 | 5.0 | 4.0 | 5.0 | 5.0 | 4.8 | 4.3 | 6.0 | 7.0 | 6.8 | 6.7 |
| | 0.25% $O_2$ | 5.0 | 4.8 | 4.6 | 4.6 | 5.0 | 4.7 | 4.0 | 4.5 | 6.5 | 6.8 | 5.8 | 6.3 |
| | 0.02% $O_2$ | 4.5 | 5.0 | 4.5 | 4.8 | 5.0 | 4.8 | 4.0 | 4.6 | 6.5 | 6.5 | 4.8 | 4.2 |
| LSD at 5% | | ← 0.8 → | | | | ← 0.8 → | | | | ← 0.7 → | | | |
| 5 | Air | 5.0 | 3.8 | 1.7 | 1.0 | 4.5 | 3.7 | 1.0 | 1.0 | 5.7 | 6.0 | 3.7 | 3.5 |
| | 0.25% $O_2$ | 5.0 | 4.8 | 3.2 | 2.7 | 4.8 | 4.7 | 3.5 | 3.6 | 6.2 | 6.3 | 3.7 | 3.5 |
| | 0.02% $O_2$ | 5.0 | 4.9 | 4.9 | 1.8 | 4.7 | 4.8 | 4.8 | 1.8 | 6.2 | 6.7 | 4.0 | 3.3 |
| LSD at 5% | | ← 1.0 → | | | | ← 1.1 → | | | | ← 0.8 → | | | |

[1]Appearance was scored using a scale of 1 to 5 where 5 is excellent, 4 is good, 3 is fair, 2 is slight defects, and 1 is severe defects.
[2]Flavor was estimated using a scale of 1 to 7 where 7 is excellent, 6 is good, 5 is fair, 4 is slight off-flavor, 3 is moderate off-flavor, 2 is severe off-flavor, and 1 is extreme off-flavor.
[3]Days under treatment.

0.02% $O_2$ at 5 °C retarded deterioration of both external and internal appearances resulting from the occurrence of internal breakdown and decay.

Soluble solids content did not change much during the experiment and it was not significantly influenced by temperature and $O_2$ concentration (Figs. 2A and 2B). Generally titratable acidity decreased and pH increased with time (Figs. 2C–F). The low $O_2$ treatments retarded the decrease in titratable acidity and the increase in pH at 5 °C, but the effects were less obvious at 0 °C.

When peaches were stored at 0 °C, 0.02% $O_2$ increased ethanol and acetaldehyde contents, but 0.25% $O_2$ did not (Figs. 3A and 3C). When the fruits were stored at 5 °C, both 0.25 and 0.02% $O_2$ increased ethanol and acetaldehyde concentrations, but the effects of 0.02% $O_2$ were greater than those of 0.25% $O_2$ (Figs. 3B and 3D). The range of ethanol levels was about 100 times higher than that of the acetaldehyde levels. While low concentrations of ethanol and acetaldehyde can enhance sensory quality (Morris et al., 1979; Paz et al., 1981), too high concentrations of these volatiles may be detrimental to the quality of fruits and vegetables (Smagula and Bramlage, 1977).

The flavor of the peaches stored in air or 0.25% $O_2$ at 0 °C for up to 40 days was good to excellent (Table 2). The flavor of the fruits stored in 0.02% $O_2$ at 0 °C was good after 7–14 days; but the flavor score decreased to fair after 29 days and to occasional off-flavor after 40 days, which was probably caused by the accumulation of ethanol and acetaldehyde. The flavor of the fruits stored at 5 °C was still good after 7–14 days in air, 0.25 or 0.02% $O_2$; after 29

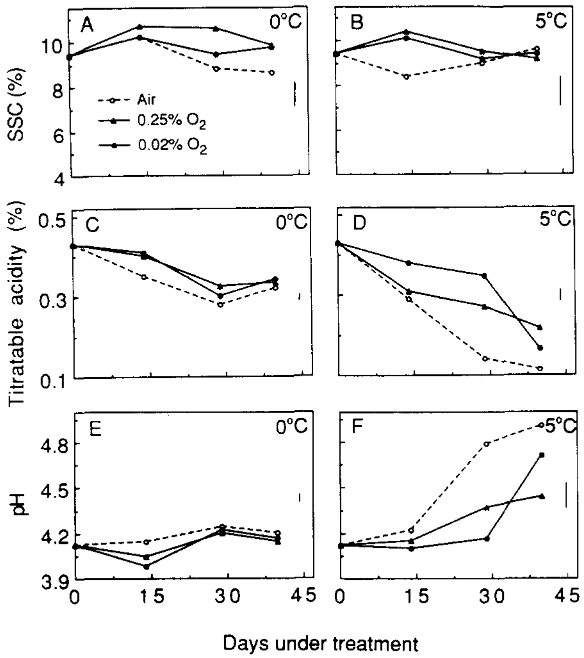


Fig. 2. Effects of storage temperature and $O_2$ level on soluble solids content (SSC), titratable acidity, and pH of 'Fairtime' peaches. The fruits were kept in air and in 0.25 or 0.02% $O_2$ at 0 or 5°C for 7, 14, 29, or 40 days followed by transfer to air at 0°C for 7 days and then to air at 20°C for 3 days. The vertical bars represent LSD values at $P=0.05$.

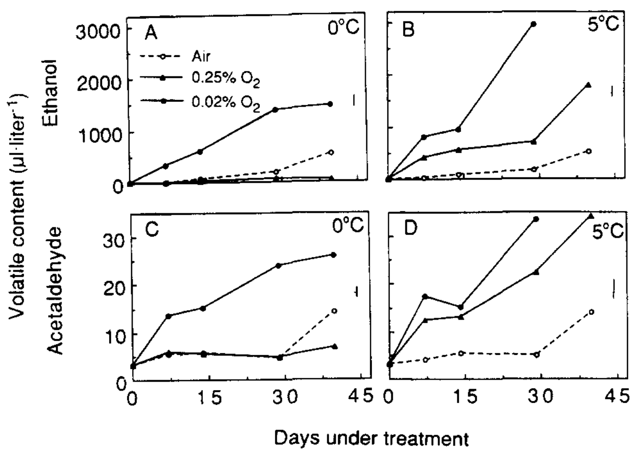


Fig. 3. Effects of storage temperature and $O_2$ level on ethanol and acetaldehyde contents of 'Fairtime' peaches. The fruits were kept in air and in 0.25 or 0.02% $O_2$ at 0 or 5°C for 7, 14, 29, or 40 days followed by transfer to air at 0°C for 7 days and then to air at 20°C for 3 days. The vertical bars represent LSD values at $P=0.05$.

days, however, the flavor scores were below acceptable levels. The decrease in flavor scores of the peaches stored in air at 5°C might have resulted from chilling injury (internal breakdown), but for the fruits exposed to low $O_2$ atmospheres at 5°C, both the occurrence of internal breakdown and the accumulation of ethanol and acetaldehyde might have contributed to the decrease in flavor scores.

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