Carbon Dioxide Injury and Flesh Softening Following High-temperature Conditioning in Peaches

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Abstract. 'High-temperature controlled-atmosphere (high CO₂/low O₂) conditioning was investigated as a possible treatment to delay the incidence of internal breakdown of peaches and nectarines (*Prunus persica* L. Batsch) during subsequent cold storage. Maintaining an atmosphere of 5% to 15% CO₂ added to air or to 1% to 5% O₂ while conditioning peaches for 2 days at 20C partially prevented fruit ripening (compared to fruit conditioned in air), as measured by flesh softening and loss of green pigment, while no off-flavors were detected. Conditioning of peaches at 20C for 4 days in air or in air + 20% CO₂ was detrimental to fruit quality, as indicated by flesh softening or detection of off-flavors.

High-temperature controlled-atmosphere (CA) conditioning is currently being investigated in our laboratory as a possible treatment to delay the incidence and reduce the severity of internal breakdown of peaches and nectarines during subsequent cold storage. The relative tolerance to short-term exposure to high CO₂ has been examined for various commodities (Allen, 1939; Hatton et al., 1975; Lange and Fica, 1984; Wang and Mellenthin, 1975; Wills et al., 1979). Short-term exposure to CA before storage lowered respiration rates and retained flesh firmness of many commodities (Bramlage et al., 1977; Herner, 1987; Kader, 1986; Lange and Fica, 1984). Increased CO₂ appears to be more effective than decreased O₂ in firmness retention (Kader, 1986).

The concentrations of CO₂ and O₂ that cause injury have been reported for various fruits and vegetables (Kader and Morris, 1977; Loughheed, 1987; Wills et al., 1979). Duration under CA and holding temperature may influence the concentrations at which CO₂ becomes injurious to a commodity (Wang and Mellenthin, 1975). Observed CO₂ injury symptoms include: external and internal browning, off-flavors and odors, and changes in susceptibility to disorders (Herner, 1987; Loughheed, 1987). All CA studies with stone fruit have been performed at low temperature (Anderson and Hardenburg, 1977). It was unknown how these fruit would react to high CO₂ levels at 20C.

We attempted to determine whether certain levels of CO₂ and O₂ would slow fruit ripening and flesh softening during conditioning without causing significant injury. The effects of short exposure to various CO₂ and O₂ levels at 20C were investigated on 'Suncrest' and 'Elegant Lady' peaches.

Fruit were obtained from an orchard near

Winters, Calif., and were sorted for uniformity of size (7 to 9 cm in diameter) and maturity (immature and soft fruit were eliminated, fruit with uniform background color were used) and freedom from mechanical injury, insect and disease damage, and cracks. Fruit were dipped for 30 sec in a fungicidal solution containing 0.6 g methyl-1-(butyl-carbamoyl)-2-benzimidazolecarbamate (benomyl)/liter plus 1.2 g 2,4-dichloro-6-nitroaniline (botran)/liter. The fruit were then placed in plastic drums, exposed to conditioning atmospheres shown in Table 1, and subsequently stored in boxes with loosely closed polyethylene liners in air at 0C. The CA conditions were achieved using a continuous-flow gas mixing system. Since the 'Suncrest' peaches did not show any injury when 15% CO₂ was used during conditioning, higher CO₂ levels were used during the subsequent 'Elegant Lady' experiment. The concentrations of O₂ and CO₂ were monitored using a Carle gas chromatography (Model 111; Carle Instruments, Anaheim, Calif.) equipped with a thermal conductivity detector. Gases were maintained within $\pm 0.2\%$ of the desired concentrations.

Quality evaluations were performed after the fruit were taken out of cold storage and again following ripening. The loss of greenness, expressed as the Gardner 'a' value, was measured in a representative area of the fruit surface (without red coloration, whenever possible) using a Gardner XL-23 Tristimulus colorimeter (Gardner Laboratory, Bethesda, Md.). The 'a' value increases as fruit yellows. Skin was removed from the two cheeks, and two flesh firmness measurements per fruit were made using a U.C. firmness tester (Western Industrial Supply Co., San Francisco) with an 8-mm-diameter cylindrical tip. For all fruit evaluations, there were three replications per treatment and five fruit per replication.

Respiration and ethylene production of six randomly selected fruit were determined following the 2- and 4-day conditioning treatments. The fruit were placed individually in

jars ventilated with a flowing air stream of ≈ 2.5 liters·h⁻¹. The concentration of CO₂ in the samples was measured with a Horiba infrared CO₂ gas analyzer (Model SX-2, PIR-2000R; Horiba Instruments, Irvine, Calif.), and the concentration of C₂H₄ with a Carle gas chromatography (Model 211; Carle Instruments) equipped with a flame ionization detector.

Following the CA treatments, the fruit were stored at 0C for 8 ('Suncrest') or 9 days ('Elegant Lady'). After storage, the fruit were allowed to reach room temperature (≈ 22 C). One-half of the fruit of each sample were evaluated for quality. The remaining fruit were evaluated after 4 to 5 days at 20C. In addition to the quality criteria described above, fruit from the CA treatments were also examined for surface pitting. They were then cut transversely to the plane of the suture, and the extent of flesh browning and 'bleeding' (red pigment in the mesocarp area) was measured. An informal taste panel consisting of four tasters evaluated peach flavor, presence of off-flavors, and overall acceptability. After ripening of the remaining fruit, flesh firmness was measured, and the external and internal appearance and flavor were evaluated. One factor analysis of variance was calculated, and Duncan's mean separation and LSD values are presented.

For the 'Suncrest' peaches, the skin color (Gardner 'a' value) before ripening was greenest (but not always significantly) in the 0C control (no conditioning), 1% O₂ + 5% CO₂ conditioning at 20C for 2 days, and 15% CO₂ conditioning at 20C for 2 days treatments (Table 1). For the 'Elegant Lady' peaches, the 0C control fruit were greenest (Table 1). Thus, conditioning at 20C in air for the indicated duration and conditions did not inhibit normal color development. These results agree with previously reported work (Isenberg, 1979).

The treatments did not affect the following characteristics: flesh color (Tristimulus colorimeter 'a' value), soluble solids content, titratable acidity, and pH (data not shown).

'Suncrest' and 'Elegant Lady' peaches previously conditioned for 2 days in air (then stored for 8 to 9 days at 0C) softened excessively; 'Suncrest' fruit conditioned for 4 days in air was even softer (Table 1). All 'Suncrest' peaches that were conditioned for 4 days were significantly softer than those conditioned for 2 days, except that those conditioned for 2 or 4 days in 1% O₂ + 5% CO₂ were of equal firmness. When 'Elegant Lady' peaches were conditioned for 4 days in 15% CO₂, the flesh firmness remained high. In general, the nonconditioned fruit, and those conditioned in 1% O₂ or > 15% CO₂, were most firm after storage, but were not significantly different from those in most other treatments. These results agree with previously published work with strawberries, bushberries, apples, and other horticultural commodities (Kader, 1986; Looney, 1975).

Flesh firmness measurements taken after 4 to 5 days ripening in air at 20C were similar for all treatments (data not presented).

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Table 1. Effect of various atmospheres applied during 20C conditioning followed by 0C air storage on the external color and flesh firmness of 'Suncrest' and 'Elegant Lady' peaches.^{a,b}

Suncrest					Elegant Lady				
Conditioning treatments			Skin color (<i>a'</i> value)	Flesh firmness (N)	Conditioning treatments			Skin color (<i>a'</i> value)	Flesh firmness (N)
O ₂ (%)	CO ₂ (%)	Days			O ₂ (%)	CO ₂ (%)	Days		
At harvest			10.1 b	58.3 a	At harvest			8.2 c	66.0 a
21	0	0	11.5 b	61.1 a	21	0	-0	19.6 b	66.0 a
21	0	2	17.5 a	31.6 d	21	0	2	28.2 a	44.3 b
21	0	4	17.3 a	13.6 e	1	5	2	24.1 ab	65.6 a
1	5	2	11.6 b	50.9 bc	1	5	4	24.6 ab	63.4 a
1	5	4	15.6 ab	51.5 bc	5	5	2	27.3 a	63.2 a
5	5	2	15.9 ab	49.2 bc	20	5	2	27.9 a	56.3 a
5	5	4	17.3 a	33.4 d	19	10	2	22.9 ab	62.9 a
20	5	2	16.3 ab	33.4 c	18	15	2	23.8 ab	63.0 a
19	10	2	18.4 a	46.4 C	18	15	4	26.6 a	54.6 a
19	10	4	17.8 a	35.7 d	17	20	2	29.3 a	64.4 a
18	15	2	12.1 b	55.8 ab	15	30	2	27.8 a	65.2 a
L S D _{P=0.05} ^c			4.4	7.6				5.5	10.1

^aMeasurements were taken after 8 and 9 days storage at 0C for 'Suncrest' and 'Elegant Lady', respectively.

^bMeasurements followed by the same letter are not significantly different.

^cWith one factor analysis of variance over treatment.

Table 2. Effect of various atmospheres applied during 20C conditioning followed by 0C air storage on off-flavor and mealiness development of 'Suncrest' and 'Elegant Lady' peaches.

Suncrest ^a				Elegant Lady ^a				
Conditioning treatments			Off-flavor ^b	Conditioning treatments			Off-flavor	Mealy
O ₂ (%)	CO ₂ (%)	Days		O ₂ (%)	CO ₂ (%)	Days		
21	0	0		21	0	0		
21	0	2		21	0	2		
21	0	4		1	5	2		
1	5	2		1	5	4	+	+
1	5	4	+	5	5	2	+	+
5	5	2		20	5	2		
5	5	4	+	19	10	2		
20	5	2		18	15	2	+	
19	10	2		18	15	4	+	+
19	10	4	+	17	20	2	+	+
18	15	2		15	30	2	+	+

^aRatings were taken after 8 days storage at 0C followed by 5 days at 20C.

^bRatings were taken after 9 days storage at 0C followed by 4 days at 20C.

^cRatings of off-flavor and mealiness: + = moderate, ++ = severe.

This observation suggests that the CA conditioning treatment had no residual effect on fruit ripening. Published work suggests that a residual effect of CA on ripening is often, but not always, observed (Kader, 1986).

Production rates for CO₂ and C₂H₄ of individual fruit immediately after the conditioning treatment were not significantly affected by CA treatments (not shown). This result contrasts with the generally recognized effects of high CO₂ on inhibiting C₂H₄ production and action and on slowing respiratory activity of fruit (Chaves and Tomas, 1984; Herner, 1987).

Fruit conditioned in reduced O₂ and elevated CO₂ for 4 days had developed off-flavors (Table 2). Both mealiness and off-flavors were detected in 'Elegant Lady' fruit at CO₂ concentrations higher than 15%.

Peaches that were conditioned for 2 or 4 days in air at 20C became excessively soft and showed substantial loss of external greenness. Softening and off-flavor development were unacceptable with fruit conditioned under CA for 4 days; thus, conditioning for 4 days at 20C is precluded. Levels of CO₂ higher than 15% during conditioning

were detrimental to fruit quality even after 2 days of conditioning. We conclude that conditioning of peaches at 20C for 2 days should be accompanied by an atmosphere containing 5% to 15% CO₂ added to air or to 1% to 5% O₂, so that flesh firmness and changes in greenness are partially inhibited, without detrimental effects on fruit flavor. The value of these conditioning treatments in relation to their effect on the incidence and severity of internal breakdown of peaches during subsequent cold storage remains to be evaluated.

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