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Long-Term Storage of Peaches and Nectarines Intermittently Warmed during Controlled-Atmosphere Storage[1]

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***Abstract*. Peaches and nectarines [*Prunus persica* (L.) Batsch] ripened at 18° to 20°C after storage in air for 9 weeks at 0° developed severe internal breakdown and were of very poor quality. Comparable fruit intermittently warmed (IW) for 2 days in air at 18° to 20° during storage at 0° in CA (1% O_2 + 5% CO_2) and then ripened generally had little breakdown and retained good quality for about 20 weeks. Less mature fruit (6.8 kg at harvest) were more acid after storage than were more mature fruit (5.5 kg at harvest). Fruit dipped in benomyl at each IW treatment had no less decay than those dipped only before storage but they had a better internal appearance and were more acid. Fruit stored in CA after 2 weeks delay in 0° air generally were poorer in quality than those stored in CA within 2 or 3 days of harvest.**

Peaches or nectarines that are stored too long at low temperatures (0–5°C) usually fail to ripen satisfactorily when transferred to higher temperatures, often becoming woolly (6) and/or developing various degrees of internal breakdown after only 3–4 weeks in storage. Also, flavor, texture, and appearance may deteriorate to the extent that the fruit are no longer marketable (8).

These disorders can be reduced, and fruit quality maintained for longer times, by delayed storage, i.e., holding fruit in air at room temperature for 1 or more days before placing them in cold storage (6, 7, 10, 11), by storing the fruit in a controlled atmosphere (CA) rather than in air (1, 5, 9, 12, 13, 14, 15), or by intermittently warming the fruit during low-temperature storage in air (2, 4, 16). An even more effective method of reducing breakdown is to combine CA storage with intermittent warming. Peaches and nectarines that were intermittently warmed (IW) during 9 weeks of 0°C CA storage had less breakdown and a better internal appearance than fruit stored in CA with no warming, or in air with or without warming (2).

Though peaches IW during CA storage retain better quality than similar fruit stored in air, the quality does change with time in storage. Some of these changes have been described in a recent study by Watada et al. (18).

The present study evaluates the response, particularly regarding breakdown, of peaches and nectarines to storage under CA and IW conditions for periods of 9 weeks and longer. Also evaluated were fruit maturity, delayed CA storage, and multiple decay control treatments, variables that could affect fruit response under these storage conditions.

Materials and Methods

'Rio Oso Gem' peaches from 2 different orchards and 'Regal Grand' nectarines from 1 orchard were tested for 2 seasons, and 'Redskin' peaches from 1 orchard were tested for 1 season. To obtain fruits of 2 maturities each cultivar was harvested twice, about 1 week apart. Only sound fruit of uniform maturity were used. At harvest fruit firmness averaged 6.8 and 5.5 kg, acidity 878 and 810 mg/100 g (as malic acid), and respiration rates 44 and 45 mg CO_2/kg-hr for the less mature and more mature fruits, respectively. The fruit were transported from commercial orchards in New Jersey, Maryland, and Pennsylvania to Beltsville on the day of harvest. Most lots of fruit were placed under test conditions within 1 day of harvest and all but the delayed storage lots were under test conditions within 3 days after harvest.

Randomized samples of 40 fruit from each harvest of each cultivar were dipped prior to storage in a 100 ppm suspension of benomyl [methyl 1-(butyl-carbamoyl)-2-benzimidazolecarbamate] at 46°C for 2.5 min for decay control (17). After drying, samples were placed in deep-cell pulpboard trays, each holding 20 fruit, to minimize bruising and facilitate handling. These trays were then placed in storage under 1 of 4 test conditions (see Table 1).

Fruit given CA + IW treatment were stored at 0°C in 1% O_2 + 5% CO_2 established and monitored as described previously (2) and were warmed every 4 weeks in air. For the IW treatment, samples of fruit were transferred from 0° CA to 0° air and the room temperature was brought to 18–20° in about 12 hr with a heater.

Table 1. Internal appearance ratings of peaches and nectarines ripened after storage in various treatments.

Storage treatment	Internal appearance rating[z] Weeks in storage[y] 9	15	20
CA + IW	86ab	80ab	68b
Delayed CA + IW	80b	68b	—
CA + IW + BEN	94a	88a	83a
Air	21c	—	—

[z]Rating: 100 = excellent appearance (no breakdown), 20 = very severe internal breakdown.
[y]Compare means within individual weeks in storage only.

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After a total of 2 days warming, the fruit were returned to CA conditions at 0°. This gradual warming minimized moisture condensation on the fruit and greatly reduced skin injury. In previous tests, intermittently warmed fruit showed skin injury more often than did non-warmed fruit (2).

Fruit in the delayed CA + IW treatment were held at 0°C in air for 2 weeks, then given an IW treatment and placed in CA storage. The fruit were warmed every 4 weeks after the initial IW treatment. Fruit in the CA + IW + benomyl treatment were dipped in a suspension of 100 ppm benomyl at 46° for 2.5 min during each IW treatment. Air-stored fruit were held at 0° continuously.

Fruit were held for 9, 15, or 20 weeks under each treatment and then ripened in air at 18° – 20°C. All fruit were ripened for a combined total of 8 to 10 days either during (IW treatments) or after storage, to provide, as near as possible, equal times at ripening temperature before final quality evaluations were made. The internal appearance of the fruit was rated on a scale of 100 to 20, where 100 indicated no internal breakdown and 20 very severe internal breakdown (2). Decay counts were also made after storage and respiration and acidity were measured both at harvest and after storage, as previously described (1).

Results and Discussion

The internal appearance of peaches and nectarines ripened after storage in air for 9 weeks was extremely poor because of internal breakdown (Table 1). In these fruit, the flesh was badly discolored and had become mealy or developed a watery, grey or brownish breakdown about the stone. Fruit stored in CA, delayed or otherwise, had a good to very good internal appearance rating and essentially no breakdown.

After 15 weeks, fruit stored in CA within 3 days of harvest had a better appearance than those placed in CA storage after a 2-week delay but only the CA + IW + BEN lots had a significantly better appearance than the delayed CA lots. Data on air-stored fruit were not included beyond 9 weeks because of severe decay. The internal appearance after 15 weeks in storage did not differ between maturities when the fruit were placed in CA storage within 3 days of harvest (Table 2). However, when storage in CA was delayed for 2 weeks, the more mature fruit developed significantly more internal breakdown than the less mature fruit.

After 20 weeks in storage (Tables 1 and 3), CA fruit treated with benomyl at each warming developed less breakdown during ripening than CA fruit not treated with benomyl at each warming. This difference might be due to the benomyl itself, the additional heat provided by the 46°C dip, or a combination of the 2 effects.

Titratable acidity declined significantly with time in storage (Table 4). Fruit given delayed CA treatment were significantly lower in acidity than either of those lots of fruit stored in CA within 3 days of harvest; acidity is significantly less in air-stored fruit than in fruit stored in CA with or without a warming treatment (2). Acidity of the fruit was related to fruit maturity. Less mature fruit were more acid (878 mg/100 g) than the more mature fruit (810 mg/100 g) at harvest and these differences persisted after all storage periods.

The respiration rate of fruit after 9 weeks of storage differed among treatments (Table 5). Air-stored fruit had a significantly higher respiration rate than any of the fruit stored in CA. Fruit given the delayed CA treatment had a higher respiration rate than either lot of fruit stored in CA within 3 days of harvest. Treatment differences were similar after 15 and 20 weeks as well (data not shown). Fruit maturity did not influence respiration rate after any of the storage periods.

Decay, mostly brown rot caused by *Monilinia fructicola* (Wint.) Honey, ranged from about 4 to 21% in fruit ripened after storage for 9 weeks in the different storage conditions (Table 6). After storage in air for 15 and 20 weeks 62 and 86%, respectively, of the fruit decayed during ripening (data not shown). When storage in CA was delayed the more mature fruit developed significantly more decay after 15 weeks than did the less mature fruit (Table 6). When storage in CA was not delayed there were no differences in the amount of decay between fruit of the 2 maturities until the fruit had been stored for 20 weeks, at which time the more mature fruit developed more decay than the less mature fruit. Treating with benomyl at each warm up was no more effective at reducing decay than a single prestorage dip.

Table 2. Internal appearance ratings of peaches and nectarines ripened after storage for 15 weeks.

Storage treatment	Internal appearance rating[z] Maturity 1	2
CA + IW	80a	79a
Delayed CA + IW	77a	58b
CA + IW + BEN	91a	85a

[z]Rating of 100 = excellent appearance (no breakdown), 20 = very severe internal breakdown.

Table 3. Internal appearance ratings of peaches and nectarines ripened after storage for 9, 15, and 20 weeks.

Storage treatment	Internal appearance rating[z] Maturity 1	2
CA + IW	79a	76b
CA + IW +BEN	91a	86a
Mean	85a	81a

[z]Rating of 100 = excellent appearance (no breakdown), 20 = very severe internal breakdown.

Table 4. Titratable acidity of peaches and nectarines ripened after storage.

Storage treatment	Titratable acidity (mg malic acid/100g) Weeks in storage[z] 9	15	Maturity[y] 1	2	Mean
CA + IW	700ab	656cd	730b	625d	678b
Delayed CA + IW	640d	587e	677c	550e	613c
CA + IW + BEN	729a	690bc	773a	646cd	709a
Mean	689a	644b	727a	607b	

[z]Maturity 1 and 2 data combined.
[y]Nine and 15 week data combined.

Table 5. Respiration rates of peaches and nectarines during ripening after storage for 9 weeks.

Storage treatment	Respiration rate[z] (mg CO_2/kg-hr.) Maturity 1	2	Mean
CA + IW	40bc	42bc	41c
Delayed CA + IW	47b	48b	47b
CA + IW + BEN	35c	38c	36c
Air	80a	74a	77a
Mean	50a	50a	

[z]Respiration in air at 18° to 20°C.

Table 6. Percentage of peaches and nectarines decayed during ripening after storage for 9, 15, or 20 weeks[z].

Storage treatment	Decay (%) 9 wk maturity 1	9 wk maturity 2	15 wk maturity 1	15 wk maturity 2	20 wk maturity 1	20 wk maturity 2
CA + IW	7.9a	8.2a	6.1bc	10.4bc	7.5b	27.9a
Delayed CA + IW	8.2a	21.1a	17.5b	34.7a	—	—
CA + IW + BEN	3.9a	6.1a	2.9c	10.0bc	5.4b	25.0a
Air	7.9a	19.6a	—	—	—	—

[z]Compare within individual weeks in storage only.

By warming peaches or nectarines during storage at 0°C in CA the storage life of these fruit can be extended several fold over that possible in normal air storage, insofar as breakdown of these cultivars is concerned. But where or when does breakdown limit the market life or consumer acceptability of these fruit? This question needs further research. The answer would seem to depend upon the intended use for the fruit. Eating a fresh peach or nectarine would probably allow only minimal breakdown, or in the system used a rating of 75 or higher would be desirable, while for processing a somewhat lower rating may be acceptable. Such ratings probably should be established by consumer and processor acceptance testing.

Within the range of maturities tested, it appeared that more breakdown and decay would be expected in the more mature fruit when storage in CA was delayed for 2 weeks. However, when storage in CA was not delayed there was no difference between maturities in the amount of breakdown that occurred. Also, the more mature fruit were lower in acidity than the less mature fruit whether storage in CA was delayed or not.

Although the multiple decay control dips were no more effective in controlling decay than the single prestorage dip they did provide some unexpected results. Fruit having the multiple dips had less breakdown and were more acid than those having the single dip. Why this occurred was not determined. Further studies on the effects of benomyl and heat on peaches and perhaps other fruit would be desirable.

For intermittent warming during storage in CA to be useful to the peach industry, scaled-up testing will be necessary. One such effort on a small scale did confirm laboratory results with regard to breakdown but severe decay caused by *Mucor albo-ater* Naumov caused the test to be terminated after storage for only 6 weeks (3). In a subsequent test on a slightly larger scale wide temperature fluctuations occurred in the commercial storage and this caused early termination of this test (unpublished report).

Internal breakdown of peaches and nectarines can be delayed by CA + IW storage, and, with respect to internal breakdown, the storage life of these fruit can be extended considerably over that possible in normal air storage but before CA + IW storage can be adopted by industry a number of problems remain to be resolved. Some of these problems have been noted in this report.

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