Low-Oxygen High-Carbon Dioxide Controlled Atmosphere Storage for Control of Anthracnose and Chilling Injury of Avocados

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ABSTRACT

Controlled-atmosphere (CA) storage of fruit of cold-sensitive avocados (*Persea americana* 'Fuchs' and 'Waldin') in 2% O_2 + 10% CO_2 for 3-4 weeks prevented development of both anthracnose (*Colletotrichum gloeosporioides*) and chilling injury at 7.2 C. All fruit were acceptable for consumption after storage in the CA followed by softening in air at 21.1 C, whereas none were acceptable after storage in air. Controlled atmospheres of low-O_2 (2%) without CO_2 or high-CO_2 (10%) with normal-O_2 (21%) were more effective than air alone (21% O_2), but not as effective as the combination of 2% O_2 + 10% CO_2 for control of decay and chilling injury. The CA reduced, but did not prevent, chilling injury of Fuchs avocados at 4.4 C, and decay was much higher at 10.0 C than at 7.2 C. Waldin avocados stored in 2% O_2 + 10% CO_2 at 7.2 C were 80% acceptable after storage for 6 weeks followed by softening at 21.1 C, a storage period three times the average storage life in air.

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Additional key words: low-temperature injury, modified atmosphere.

The principal problems encountered in storage of Florida avocados are anthracnose decay (caused by *Colletotrichum gloeosporioides* Penz.) and chilling injury (3). Storage at 12.8 C to avoid chilling injury hastens ripening and the development of anthracnose. Storage of avocados (cultivar Taylor) for 3 weeks at 4.4 C in air containing 10% CO_2 suppressed chilling injury (6). Lula and Booth 8 avocados developed less decay and less chilling injury at 4.4 or 7.2 C when stored for 40 or 60 days in a controlled atmosphere (CA) of 1% or 2% O_2 with 9 or 10% CO_2 than in air (2, 4, 5). However, the relative contributions of low-O_2 and high-CO_2 concentrations for control of decay and chilling injury of avocados have not been clarified.

This paper reports the individual effects of low-O_2 and high-CO_2 on the development of chilling injury, and on anthracnose decay of avocados. Preliminary tests run with Lula and Hall avocados stored at 7.2 C for 5 weeks, showed that both 2% O_2 and 10% CO_2 were needed to control decay and chilling injury. However, since chilling injury does not develop as quickly or as severely in cold-tolerant cultivars (e.g., cultivars Lula and Hall) as in cold-sensitive West Indian cultivars (e.g., cultivars Fuchs and Waldin) these latter cultivars were used in the final evaluations reported here. Additional information is also provided on the time-temperature parameters for quality maintenance of avocados in CA's, and on the potential for long-term storage of avocados in CA.

MATERIALS AND METHODS.—Mature fruit of Fuchs and Waldin avocado cultivars were obtained on the day of harvest from packinghouses in the Homestead, Florida, area during the 1972 and 1973 seasons. Lots from three growers were used as replicates. Fruit for each test were divided into comparable samples by weight of individual fruit. One sample from each lot was placed at 21.1 C to determine softening time and quality before storage. Ten fruit from each lot were placed in chambers containing an atmosphere of low-O_2 (2%) or normal-O_2 (21%), with and without high-CO_2 (10%), for 3 (Fuchs) or 4 (Waldin) weeks at 7.2 C. The terms "low-O_2" and "high-CO_2" are relative to normal concentrations of these gases in air, in which O_2 is 21% and CO_2 is 0.03%. Fruit were then softened in air at 21.1 C for 1 week. Data for Fuchs and Waldin avocados did not differ significantly and were averaged together. The same basic procedure was followed for storage of Fuchs avocados at 4.4, 7.2, and 10.0 C for 3 weeks and storage of Waldin avocados at 7.2 C for 6 weeks in air or 2% O_2 + 10% CO_2 followed by softening in air at 21.1 C. Generally fruit free of scratches and decay were used in storage studies. However, to provide a more rigorous test of prolonged storage of Waldin avocados, "field-run" fruit of acceptable appearance, but with scratches and traces of decay (index rating = 0.4), were used.

Specifications of the CA chambers, methods used to maintain and analyze atmospheres, and methods of rating decay and chilling injury were as previously described (5). Decay and chilling injury, were rated on removal of fruit from storage, and again after softening in air. Severity of symptoms were rated as 0 (none), 1 (trace), 2 (slight), 3 (moderate), and 4 (severe). Avocados with moderate or severe decay or chilling injury were considered unacceptable for sale and consumption.

RESULTS AND DISCUSSION.—*Individual and combined effects of low-O_2 and high-CO_2.*—The combination of low-O_2 (2%) with high-CO_2 (10%) was more effective than either alone for retarding development of anthracnose decay and chilling injury of Fuchs and Waldin avocados stored at 7.2 C for 3 and 4 weeks, respectively, and softened in air at 21.1 C (Fig. 1). Decay ratings of avocados stored in normal air (21% O_2) averaged moderate (2.8), whereas decay in low-O_2 (2%) and high-CO_2 (10%) with normal-O_2 (21%) averaged trace (1.2) and slight (1.9), respectively (Fig. 1-A). These results suggest that low-O_2 and high-CO_2 are about equally effective in partially preventing decay development. Decay of fruit in the combined low-O_2 and high-CO_2 (2% O_2 + 10% CO_2) was almost completely inhibited and ratings averaged only a trace (0.1), the approximate degree expected if the effects of low-O_2 and high-CO_2 were additive to control decay.

Avocados stored in 21% O_2 developed severe internal (4.0) and external (3.8) chilling injury (Fig. 1-B, C). Low-O_2 alone had only a slight inhibitory effect on retarding the development of chilling injury, while high-CO_2 was more effective. This ability of CO_2 to partially suppress symptoms of chilling injury supports previously reported work with cold-tolerant Taylor avocados (6). Only traces (index rating = 0.4) of injury developed in fruit in 2% O_2 + 10% CO_2, a degree of inhibition greater than could be expected if the effects of 2% O_2 and 10% CO_2 were purely additive. The inhibiting effect of high-CO_2 thus may be enhanced in a low-O_2 atmosphere.

Temperature effects.—A storage temperature of 7.2 C provided maximum control of anthracnose decay and chilling injury of Fuchs avocados in a CA of 2% O_2 + 10% CO_2 for 3 weeks, followed by softening in air at 21. 1 C (Fig. 2). Above 7.2 C, chilling injury was completely prevented in fruit stored in the CA, but significantly more anthracnose (index rating = 1.7) developed than at lower temperatures. Below 7.2 C, internal chilling injury of fruit stored in the CA was almost as severe as of fruit in air. The slightly higher average decay index at 4.4 C, than at 7.2, may be associated with slightly greater chilling injury at 4.4 C with accompanying greater susceptibility to fungal attack. Overall acceptability of fruit softened for consumption was 0, 100, and 87% after storage in the CA at 4.4, 7.2, and 10.0 C, respectively. None of the fruit stored in air were acceptable.

Effects of prolonged CA storage.—Waldin avocados stored in a CA of 2% O_2 + 10% CO_2 at 7.2 C were still firm after 6 weeks–three times the average storage life in air. Small, brown necrotic spots developed on the rind of 26.7% of the fruit. These symptoms did not seriously detract from the overall acceptable appearance of the fruit. The presence of such spots in fruit stored in air could not be ascertained because of the presence of severe anthracnose and chilling injury. Fruit from the CA became softened in air at 21.1 C in 4.4 days–2 days less than the prestorage samples. The necrotic spotting remained confined and only trace anthracnose (index rating = 1.1) and trace external chilling injury (index rating = 1.3) developed during softening. No internal chilling injury symptoms developed and overall acceptability for consumption was 80%. In contrast, fruit stored in air started to soften and developed slight decay (index rating = 1.6) and external chilling injury (index rating = 2.2) during storage. After removal, all fruit from air storage developed severe decay (index rating = 4.0) and internal chilling injury (index raing = 4.0) within 2 days at 21.1 C; none were acceptable for consumption.

The effect of the CA of 2% O_2 + 10% CO_2 in restricting decay development appears to be on the fruit rather than the fungus. Daily radial growth of *C. gloeosporioides* on four lima bean agar plates in 2% O_2 + 10% CO_2 at 21.1 C for 1 week, was only slightly less than growth on comparable plates in the air. The main difference observed was an inhibition of sporulation of the fungus in the CA. Since the anthracnose fungus infects fruit in the field, and then lies dormant until the avocado starts to soften (1), the action of the CA in slowing the rate of softening would serve to keep the fungus dormant.

Prolonged storage of Fuchs avocados would not be practical for the industry because fruit of this cultivar mature early in the season when demand is high. Waldin avocados, on the other hand, are harvested in large quantities during September, when markets are often oversupplied and ability to store production would allow orderly and profitable marketing. This study demonstrates that Waldin avocados might be stored 6 weeks under CA without significant loss from decay or chilling injury.

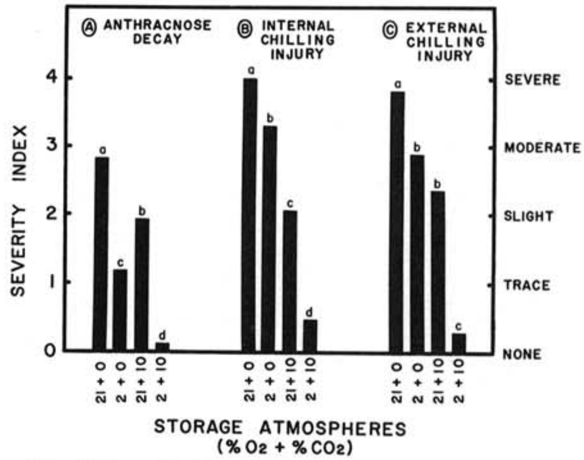

Fig. 1-(A to C). Decay and chilling injury of avocados. **A)** Average anthracnose decay, **B)** internal and **C)** external chilling injury of Fuchs and Waldin avocados stored in atmospheres containing 21% O_2 (air), 2% O_2, 21% O_2 + 10% CO_2, or 2% O_2 + 10% CO_2 for 3-4 weeks at 7.2 C, followed by softening in air at 21.1 C. Different letters indicate significant difference according to Duncan's Multiple Range Test. ($P = 0.05$).

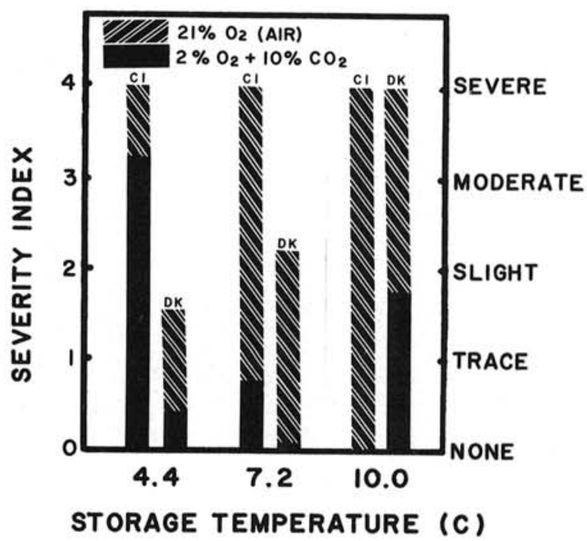

Fig. 2. Anthracnose decay (DK) and internal chilling injury (CI) of Fuchs avocados stored for 3 weeks in atmospheres containing 21% O_2 (air) or 2% O_2 + 10% CO_2 at different temperatures, followed by softening in air at 21.1 C.

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