

## Low Pressure (Hypobaric) Storage of Avocados<sup>1</sup>

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**Abstract.** 'Waldin', 'Booth 8', and 'Lula' avocados (*Persea americana* Miller) were not acceptable when softened at 21.1°C in air under normal pressure, if they had been stored for 4-6 weeks at 7.2-10.0°, 98-100% relative humidity, and an atmospheric pressure of 76, 152, or 760 mm Hg. 'Waldin' avocados were acceptable when softened after 25 days at 7.2°C and 91 mm Hg provided that storage was in 2% O<sub>2</sub> and 10% CO<sub>2</sub>. The results suggest that atmospheres both low in O<sub>2</sub> and high in CO<sub>2</sub> are necessary for the successful storage of avocados under low pressure. Under these conditions the low pressure system is comparable to the standard controlled atmosphere system in which avocados are stored in 2% O<sub>2</sub> and 10% CO<sub>2</sub> at normal atmospheric pressure.

Hypobaric or low atmospheric pressure (LP) storage is a patented method (1, 3) claimed by Burg (2) to extend "the useful life of fresh fruits, vegetables, cut flowers, cuttings, potted plants, meat, poultry, fish, shrimp, and other metabolically active matter." He reported, for example, that 'Lula' avocados remained firm for 3½ months under hypobaric conditions and then ripened normally upon removal. This length of storage under LP is almost twice that reported (4, 5) for 'Lula' avocados held in a controlled atmosphere (CA) under normal atmospheric pressure (NP). We report the effect of LP storage on decay, chilling injury (CI), and overall quality of 3 Florida avocado cultivars.

Freshly harvested 'Waldin', 'Booth 8', and 'Lula' avocados were selected free of decay and blemishes from bulk bins at local packinghouses. Avocados were sorted by weight into comparable samples of 20—25 fruit for each treatment. Decay and CI of avocados after storage and softening were rated on the basis of percentage of surface area of rind affected: 1=trace (up to 3%—barely noticeable), 2=slight (up to 10%—noticeable, but not objectionable), 3=moderate (10 to 20%—unacceptable), and 4=severe (more than 20%—unacceptable).

CA and LP storage tests were run as described previously (5, 7). Storage atmospheres were air, 2% O<sub>2</sub>, 4% O<sub>2</sub> and 2% O<sub>2</sub> with 10% CO<sub>2</sub>. To obtain the last mentioned atmosphere under LP, pure CO<sub>2</sub> and O<sub>2</sub> from gas cylinders were metered into a 150-ml glass mixing chamber and their flow rates regulated to supply a mixture of 16.7% O<sub>2</sub> and 83.3% CO<sub>2</sub> (amounts corresponding to 2% O<sub>2</sub> and 10% CO<sub>2</sub> at LP). Flow into the chamber was controlled at 110 ml/min (1 air change/hr). Oxygen concn were

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maintained at  $\pm 0.5\%$  and  $\text{CO}_2$  concn was kept at  $\pm 1\%$ . No  $\text{CO}_2$  was added to the air check, since previous studies (6) showed that  $10\% \text{CO}_2$  was not beneficial unless mixed with  $2\% \text{O}_2$ . Chamber pressures were 76, 91, 152 and 760 mm Hg and were maintained at  $\pm 2$  mm Hg. The relative humidity in each LP and NP chamber was maintained at  $98\text{--}100\%$  as determined by a humidity sensing element (Hygrodynamics, Inc., Silver Spring, MD). Temperatures reported are accurate to  $\pm 0.5^\circ\text{C}$ .

Table 1. Quality of 'Lula' avocados stored at  $10^\circ\text{C}$  and  $98\text{--}100\%$  relative humidity for 6 weeks in various atmospheres under normal (NP) or low atmospheric pressure (LP) and then softened at  $21.1^\circ$  in air under NP.<sup>z</sup>

Type	Storage conditions			Decay index <sup>y</sup>	External CI index <sup>y</sup>	Acceptable fruit <sup>x</sup> (%)
	(mm Hg)	$\text{O}_2$ (%)	$\text{CO}_2$ (%)			
NP	760	21	0	4.0	4.0	0
NP	760	2	10	1.8	0.1	70
LP	76	2	0	4.0	2.7	0
LP	152	4	0	4.0	4.0	0

<sup>z</sup>Each figure is the mean for 40 avocados (2 replications of 20 avocados per treatment).

<sup>y</sup>In the rating system for decay and CI, 0=none, 1=trace, 2=slight, 3=moderate, and 4=severe. Fruit with moderate and severe ratings were considered unacceptable.  $10\%$  of the rind, and detracted significantly from appearance.

<sup>x</sup>Acceptable fruit had good appearance, were free of moderate or severe decay and CI, and had no off-flavors.

'Lula' avocados stored at  $10^\circ\text{C}$  four weeks under all conditions of atmospheres and pressures except one (Table 1) developed severe anthracnose decay and moderate to severe external CI. Internal CI was either absent or slight. Most of the avocados stored under LP or in air ( $21\% \text{O}_2$  with  $0\% \text{CO}_2$ ) under NP were not acceptable after softening at  $21.1^\circ$ ;  $70\%$  of the avocados stored in the standard CA conditions ( $2\% \text{O}_2$  with  $10\% \text{CO}_2$ ) under NP were acceptable after softening. This atmosphere inhibited the development of decay and CI as previously shown (4, 5, 6). These avocados were hard on removal from storage and softened in 4.5 days at  $21.1^\circ$ . Results were similar to these under comparable conditions for 'Waldin' and 'Booth 8' stored 4 and 5 weeks, respectively. Storage of all 3 cultivars for 4–6 weeks at lower temp ( $4.4$  and  $7.2^\circ$ ) and at  $76$  mm Hg, but without  $\text{CO}_2$  enrichment, also resulted in unacceptable fruit.

Table 2. Quality of 'Waldin' avocados stored at  $7.2^\circ\text{C}$  for 25 days in various atmospheres under normal (NP) or low atmospheric pressure (LP) and then softened at  $21.1^\circ$  in air under NP.<sup>z</sup>

Type	Storage conditions			Wt loss (%)			Softening time (days)	Decay (%)	Chilling injury (%)	Acceptable fruit <sup>x</sup> (%)
	(mm Hg)	$\text{O}_2$ (%)	$\text{CO}_2$ (%)	Firmness before and after storage <sup>y</sup>	During storage	During softening				
	<i>Unstored fruit</i>			5.0	—	6.4	5.4	4	0	96
NP	760	21	0	4.0	2.2	1.3	1.2	76	100	0
NP	760	2	0	4.9	1.1	4.9	5.1	100	100	0
NP	760	2	10	5.0	1.1	4.9	5.0	4	4	92
LP	91	2	0	4.6	2.2	2.9	3.2	64	100	0
LP	91	2	10	5.0	3.1	3.8	3.7	0	0	100

<sup>z</sup> Each figure is the mean for 25 avocados.

<sup>y</sup> In the rating system for firmness, 5=hard, 4=firm, 3=firm ripe, 2=soft ripe, and 1=overripe.

<sup>x</sup> Acceptable fruit had good appearance, were free of moderate or severe decay and chilling injury, and had no off-flavors.

The absence of  $\text{CO}_2$ , a gas essential to the successful storage of avocados in CA, was considered to be a possible reason for the failure of avocados to store well under LP. We, therefore, tested the effect of  $\text{CO}_2$  enrichment on the ability of the LP system to

maintain the quality of avocados (Table 2). Regardless of atmospheric pressure, fruit stored in 2% O<sub>2</sub> with 10% CO<sub>2</sub> developed little decay and CI, and were mostly acceptable; whereas all fruit stored in 2% O<sub>2</sub> without CO<sub>2</sub> developed severe decay and CI, and were unacceptable. 'Waldin' avocados lost very little weight and remained firm to hard, regardless of the storage atmosphere. Weight loss during softening was proportional to the softening time. The average softening time of avocados stored at NP in 2% O<sub>2</sub> with or without CO<sub>2</sub> was similar to that of freshly-picked unstored fruit and from 1-1/3 to 4 days longer than that of fruit stored in LP with and without CO<sub>2</sub> and of fruit stored at NP in air. Fruit stored in LP without CO<sub>2</sub> often failed to soften uniformly. Weight loss and softening time for 'Waldin' avocados stored at LP in 2% O<sub>2</sub> were similar regardless of the presence or absence of CO<sub>2</sub>.

Table 3. Decay and chilling injury (CI) of 'Waldin' avocados stored at 7.2°C for 25 days in various atmospheres under normal pressure (NP) or low atmospheric pressure (LP) and then softened at 21.1°C in air under NP.<sup>z</sup>

Type	Storage conditions			Decay index <sup>y</sup>				CI Index <sup>y</sup>		
	(mm Hg)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	After storage		After softening		After storage		After softening
				Anth <sup>x</sup>	SER <sup>w</sup>	Anth	SER	External CI	External CI	Internal CI
	<i>Unstored fruit</i>			—	—	0.1	0.1	—	0.0	0.0
NP	760	21	0	1.5	0.0	3.2	0.0	0.8	2.6	4.0
NP	760	2	0	0.0	0.0	3.0	2.0	0.0	4.0	1.4
NP	760	2	10	0.5	0.0	1.0	0.0	0.0	0.7	0.0
LP	91	2	0	0.1	0.0	2.7	0.3	0.1	3.9	3.7
LP	91	2	10	0.3	0.0	0.8	0.0	0.0	0.4	0.0

<sup>z</sup>Each figure is the mean for 25 avocados.

<sup>y</sup>In the rating system for decay and CI, 0=none, 1=trace, 2=slight, 3=moderate, and 4=severe. Fruit with moderate and severe ratings were considered unacceptable.

<sup>x</sup>Anth=anthracnose.

<sup>w</sup>SER=stem-end rot.

Data for the principal decays, anthracnose (*Colletotrichum gloeosporioides* Penz.) and stem-end rot (*Diplodia natalensis* P. Evans), plus CI are presented in Table 3. Avocados stored at NP in 21% O<sub>2</sub> (air) developed more anthracnose during storage than those stored at NP or LP in 2% O<sub>2</sub> with or without CO<sub>2</sub>. No stem-end rot developed during storage in any atmosphere. Avocados stored in atmospheres without CO<sub>2</sub> developed moderate to severe anthracnose during softening, whereas fruit stored in atmospheres with 10% CO<sub>2</sub> developed only a trace. The amount of stem-end rot which developed during softening was slight for avocados stored at NP in 2% O<sub>2</sub> without CO<sub>2</sub>, but was zero to a trace for those stored in all other atmospheres. Black pitted areas developed in lenticels during softening of avocados stored at NP or LP in 2% O<sub>2</sub> chambers containing 10% CO<sub>2</sub>. However, pitting was slight and was not considered to be objectionable to the average consumer. Tissue from the infected areas contained *Pestalotia* spp. fungus.

Avocados developed more external CI during storage in air than in other atmospheres. Avocados stored at NP or LP in atmospheres without CO<sub>2</sub> developed moderate to severe external and internal CI, whereas fruit stored in atmospheres with 10% CO<sub>2</sub> developed a trace of external CI and no internal CI. Our results do not support the conclusions of others that avocados can be stored successfully at LP (2). The CO<sub>2</sub> requirement in our LP system for acceptable storage of avocados is in agreement with our earlier finding that CO<sub>2</sub> is essential in our CA system (4, 6). However, the addition of

CO<sub>2</sub> does not make the LP system superior to the CA system, but simply makes the 2 systems comparable for quality maintenance of avocados. Relative humidity does not appear to be a factor since the acceptability values of avocados stored under LP at relative humidities of 80-85% and 98—100% were not significantly different (data not shown). Whether industry should use an LP or a CA facility will depend upon which is most economical. The fact that LP, but not CA, can be used to extend the normal storage life of limes (7) provides an advantage for the LP system.

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