

SUSCEPTIBILITY OF WEST INDIAN AVOCADOS TO CHILLING INJURY AS RELATED TO RAPID COOLING WITH LOW TEMPERATURE AIR OR WATER¹

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Abstract

Removal of field heat from avocados before shipment reduces decay and retards the ripening process, thus extending market life. Some avocados, especially West Indian varieties, are subject to chilling injury when stored at temperatures lower than 55 °F. The use of low temperatures for the cooling medium can greatly reduce the time required for cooling. Such practice, however, raises the question of whether the fruit might suffer from chilling injury when cooled in this way. Studies were conducted, over a period of three seasons, on the rapid cooling of 12 West Indian varieties of avocados to determine whether this manner of cooling would cause chilling injury to the fruit. Air temps were as low as 17°F, and water temp used were as low as 33°F. Fruit were cooled to mass-average temps that generally ranged from 40° to 50°F but were as low as 33°F in one test, and were then allowed to ripen at 70°F. No definite evidence of chilling injury was found in any of the samples tested.

Removal of field heat from avocados before shipment is desirable in order to lower the respiration rate and to reduce the activity of decay-causing organisms. In addition, cooling helps to retard the ripening process, thus extending the market life. Avocados, particularly West Indian varieties, are subject to low-temperature injury—commonly called "chilling injury." Chilling injury in avocado fruits is characterized by abnormal ripening, darkening of the flesh, development of off flavors and odors, and pitting and darkening of the skin. Usually, chilling injury symptoms develop during ripening after storage at low temperatures. Detailed descriptions of chilling injury symptoms, and conditions under which chilling has occurred, have been given by a number of previous researchers (2,3,4,5 and 7).

A time-temperature relationship appears to be associated with avocado chilling injury, and some varieties are more susceptible to chilling injury than others. In some varieties, chilling injury has occurred in as few as 4 days when fruit were stored at 50°F or in 3 days when stored at 40° or 45°F. Chilling injury has even been detected in some avocados after storage at 55°F for 14 days (3).

Because chilling injury has occurred in avocados as a result of storage at temperatures lower than 55°F, use of 55°F air or water for cooling would seem a safe practice. Since cooling rate is a direct function of the difference between the temperature of the fruit

and the temperature of the cooling medium, much faster cooling rates can be obtained by using cooling medium temperatures considerably lower than 55°F. Under these conditions the fruit surface and interior flesh portions would reach temperatures much colder than 55°F, however. Rapid removal of heat in this manner may cause a thermal shock effect. Therefore, such practice raises the question of whether the fruit might suffer from chilling injury when cooled in this way. The objective of these studies was to determine if rapid cooling of avocados with low-temperature air or water would cause chilling injury to the fruit.

Fruit Cooling Characteristics

A discussion on fruit cooling characteristics is presented here in order that the reader might understand the reasons for this study. When avocados are cooled slowly, as would be the case when warm fruit are placed in a cold storage room, heat is removed under essentially steady-state conditions and there is no appreciable difference in the temps at the surface and interior flesh and seed areas during cooling. Rapid cooling can be obtained by using cooling medium temps much lower than the temp of the fruit, and by providing a high convective coefficient at the fruit surface (high air flow rate or highly agitated water). Here, heat transfer¹ occurs under transient conditions, and the center and interior portions cool more slowly than does the surface. The thermal resistance within fruits and vegetables is such that a relatively large temp gradient can occur within the product during rapid cooling. The temp that denotes the heat content of a substance at any time during transient cooling is referred to as the mass-average temp. Therefore, the mass-average temp represents a single value from the temp distribution within the fruit that would become the uniform product temp if the fruit were allowed to equilibrate without losing heat or gaining heat. A thorough discussion of the mass-average temp concept is given by Smith and Bennett (6).

The rate of heat removal during cooling of avocados will depend on the temp and flow rate of the cooling medium. Information presented in Table 1 illustrates relationships between cooling times and cooling medium temps and flow rates as calculated from experimental data. Note the highly significant reduction in cooling time that can be obtained by using high flow rates and low cooling medium temperatures.

Table 1. Time required to cool 20 oz. avocados from 90°F to 50°F or 55°F mass-average (MA) with air at different velocities and fruit in a single layer, or by submerging fruit in highly agitated chilled water.

Cooling medium	Cooling temp. (°F)	Air face velocity (fpm)	Cooling time (min.)	
			50° MA	55° MA
Air	20	100	49	40
		400	*	*
	32	100	68	54
		400	40	32
	40	100	94	70
		400	55	41
	45	100	128	88
		400	75	51
	50	100	--	121
		400	--	71
Water	32°	---	21	17
	40	---	29	22
	45	---	39	27
	50	---	--	37

* surface of fruit will go below 32°F before mass-average reaches 55°F.

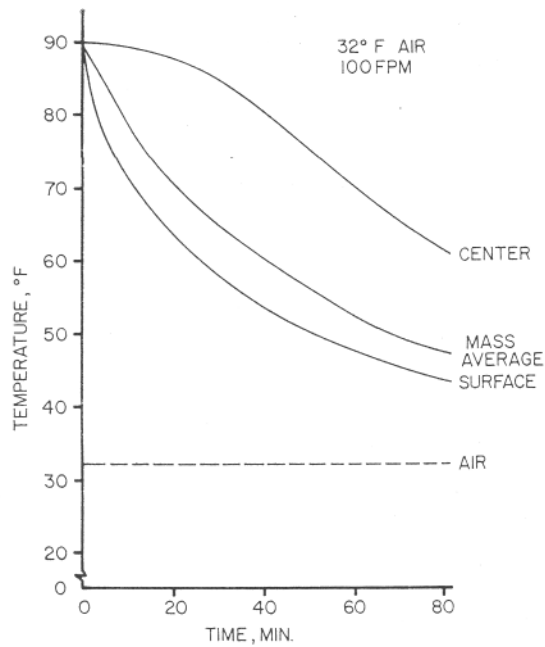


Fig. 1. Temperature response of 20 oz. avocados during cooling with 32°F air at 100 fpm face velocity, and with fruit in a single layer.

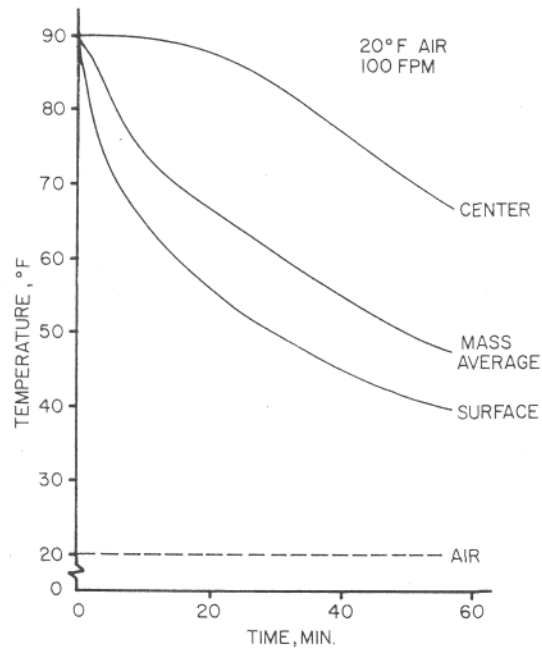


Fig. 2. Temperature response of 20 oz. avocados during cooling with 20°F air at 100 fpm face velocity, and with fruit in a single layer.

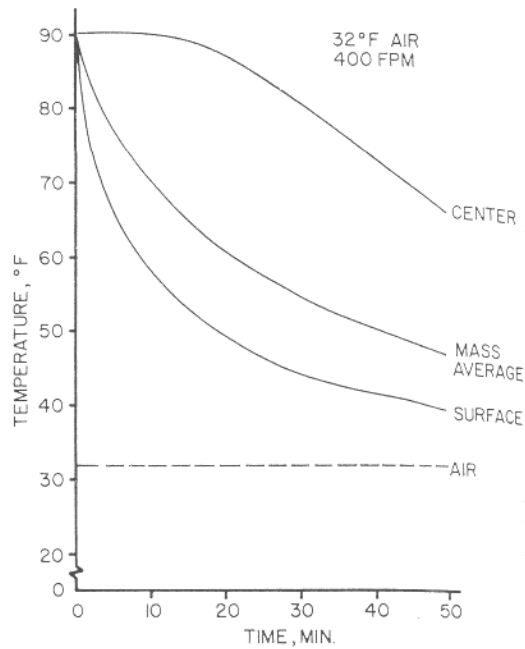


Fig. 3. Temperature response of 20 oz. avocados during cooling with 32°F air at 400 fpm face velocity, and with fruit in a single layer.

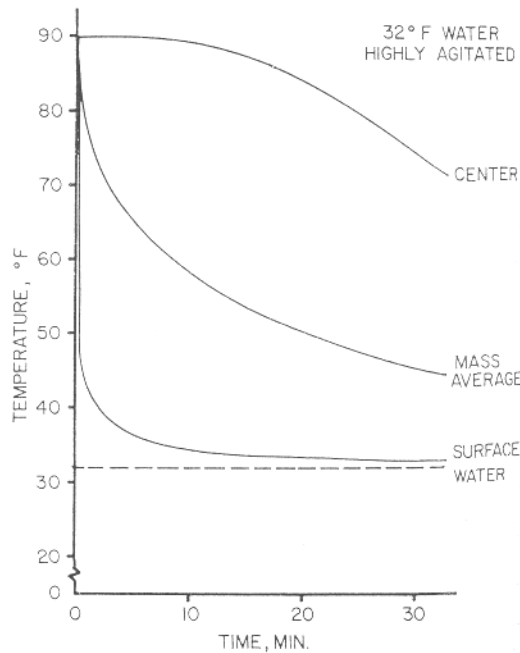


Fig. 4. Temperature response of 20 oz. avocados during cooling, with individual fruit surrounded by highly agitated 32 °F water.

Figs. 1-3 further illustrate some cooling characteristics of avocados using air at different temperatures and face velocities. These curves show measured surface, center and calculated mass-average temps from experimental tests. Figure 4 shows similar data for cooling with highly agitated 32 °F water. These figures show that where low cooling medium temperatures are used to rapidly reduce the mass-average fruit temperature to 50°F, the fruit surface and underlying portions of the flesh will get considerably lower than 50°F during cooling.

It should be noted that the data shown in Table 1 and in Figs. 1-4 represent cooling characteristics for a given size and shape of fruit. In addition, the data on air cooling are for fruit in a single layer and those for cooling with water represent information from experiments where individual fruit were entirely surrounded with highly agitated chilled water at a constant temperature for the duration of cooling. Therefore, these data should not be used to anticipate the cooling rates which would be attained under commercial conditions. In actual practice, fruit would be of a range of sizes and would likely be cooled in configurations much deeper than one layer, such as in bulk pallet loads. Under these conditions, the average cooling rate of the load would be slower than for fruit in a single layer when using either air or water.

The authors have conducted experiments on air cooling of avocados in bulk loads and in cartons. Tests on hydro cooling of avocados by spraying chilled water over the fruit in bulk loads will be completed soon. In addition, a mathematical model is under development which will describe avocado cooling rates as a function of temperature and flow rate of the cooling medium and of product size and configuration during cooling.

Experimental Procedures

Studies were conducted on rapid cooling of 12 West Indian avocado varieties with low temperature air and water. Twenty-four cooling tests were run over a period of three seasons in 1973, 1974 and 1975. Table 2 gives information on the varieties and number of fruit samples used for the various tests. For all tests, several control samples for each variety were ripened at 70°F with no prior cooling. This was done in order to have uncooled samples to compare with the rapidly cooled samples following the ripening period. In both 1974 and 1975, additional control samples were held at 33°F to determine if the particular fruit samples used in these tests were susceptible to chilling injury under severe temperature conditions. These fruit were removed from 33°F at various intervals and evaluated for chilling injury after ripening at 70°F.

Fruit samples for all of the tests were obtained from a commercial packinghouse in Homestead, Florida. Cooling tests were completed within 2 days after harvesting. For the air cooling tests, fruit were cooled in a single layer in a mesh-bottom container, using a special research unit in which the air velocity and temperature could be maintained at desired levels for the duration of each test (1). Moisture loss from the fruit was minimized by maintaining high relative humidity during cooling. The cooling tests with water were conducted in a refrigerated bath with moderate agitation in 1973 and 1974. An insulated container containing water and crushed ice, with very high agitation provided by introducing air bubbles into the bottom of the container, was used in 1975.

Table 2. Information on avocado samples used in tests to evaluate susceptibility to chilling injury as related to rapid cooling with low temperature air or water.

Test numbers	Date harvested	Fruit weight		Number of fruit, each variety			Varieties studied
		range (oz.)	average (oz.)	each cooling test	70°F control	33°F control	
1-2	8-23-73	11-40	16	1	3	--	Dawn, Dupuis, K5, Nadir, Peterson, Pollock, Ruehle, Seedling, Simmonds, Trapp, Tower 2, Waldin
3-5	9-10-73	6-19	13	1	1	--	Peterson, Trapp, Waldin
6-9	9-24-73	15-21	18	1	1	--	Peterson, Trapp, Waldin
10-15	7-28-74	14-24	19	2	3	3	Nadir, Pollock, Simmonds
16-20	9-18-74	19-23	21	6	20	10	Waldin
21-24	7-23-75	16-22	20	4	4	3	Nadir, Pollock, Ruehle, Simmonds

Prior to the start of each cooling test, fruit were warmed to a temp between 80° and 90°F to represent the relatively high temp that fruit might attain in the grove at the time of harvest. Temperatures of representative fruit samples in each test were measured with 36 gage copper constantan thermocouples connected to a digital temp recorder. Fig. 5 illustrates typical locations of thermocouples for measurement of temps at the fruit surface and interior portions during cooling. Fruit samples with thermocouples were not utilized for subsequent chilling evaluation.

A number of different air and water temps and flow rates were used for the cooling tests in order to produce various cooling rates and temperature gradients within the fruit during cooling. Also, different tests represented different amounts of cooling, that is, the fruit were cooled to a lower mass-average temp in some tests than in others. This was done to obtain a range in the severity of the cooling conditions used for the different tests.

Information on the conditions used for each of the 24 cooling tests and the final fruit surface and mass-average temps at the end of cooling is given in Table 3. A range indicated for the final temperatures means that a relatively wide range of fruit sizes was used in that test and that the temperature readings were taken from two fruit, one representing a large size and one representing a small size.

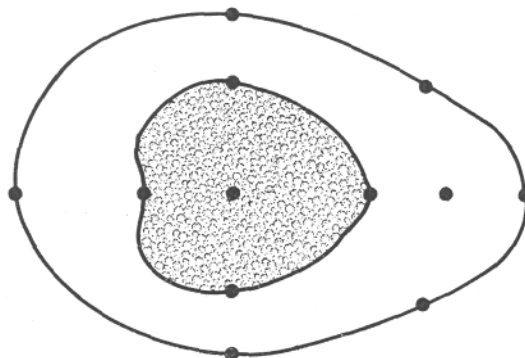


Fig. 5. Typical locations of thermocouples used for measurement of temperatures in avocados during cooling.

Following each cooling test in 1973 and 1974, fruit samples were immediately placed at 70°F for ripening. In 1975, the fruit samples were held in a 50°F room for 50 hours following cooling before being transferred to 70°F for ripening. This temporary holding at 50°F was to simulate transit conditions during shipping. It was felt that this procedure gave a more severe test than when the fruit were placed at 70°F immediately after cooling. Measurement of fruit temperatures after cooling indicated that the fruit equilibrated to approximately 50°F in 2 to 4 hours when held in cartons in the 50°F room. About 5 hrs were required for the fruit to reach 70 °F after being transferred from the 50°F room to the 70°F room. High relative humidity was maintained in the 50°F and 70°F rooms to minimize fruit weight loss and shriveling.

During ripening at 70°F, fruit were checked daily and were removed when they were soft ripe. They were then examined for both external and internal symptoms of chilling injury.

Results and Discussion

Fruit of all varieties held at 33°F in the 1974 and 1975 tests sustained chilling injury symptoms during ripening, provided the period of storage at this temperature was sufficiently long. Several samples from each variety developed chilling injury after 4 or 5

days at 33°F, whereas a few were held 8 to 12 days at this temp before they sustained chilling injury. Fruit of all varieties studied exhibited more severe chilling injury symptoms as the storage period was increased. Severe chilling injury was characterized by graying or blackening of the flesh near the vascular bundles.

None of the 175 fruit samples from any of the 24 cooling tests showed definite signs of chilling injury after ripening. A total of 8 fruit, one each from tests 6, 7, 11 and 24 and two each from tests 13 and 22 did have spotty brown or gray discoloration of the flesh. However, in each instance, several of the 70°F control samples of the same variety (which were not cooled) exhibited identical symptoms. In all instances where such discoloration occurred, both the cooled and control samples had decayed areas from diplodia or anthracnose. Therefore, the discoloration may have been related to the decay in these fruit, although it was not always directly adjacent to the decayed areas. Several of the 'Waldin' fruit from cooling tests 16-20 showed some internal browning upon examination following ripening. This could not be directly attributed to chilling, however, as about one-half of the 70°F control samples had identical browning. This is in agreement with the results found by Mustard (5), who reported a significant percentage of 'Waldin' and 'Trapp' avocados developed internal browning after they were held at room temp with no prior refrigeration.

The benefits of cooling avocados after harvest were evidenced in the present study by the condition of the samples from the cooling tests, which showed much lower levels of decay after ripening than did the 70°F control samples. Also, total ripening time for the samples that had been cooled was considerably longer than that for the 70°F control samples.

Results from this study indicated that West Indian avocado varieties, although subject to chilling injury after several days of storage at low temperatures, can be rapidly cooled to a mass-average temperature of 50° or 55°F with low temperature air or water without fear of causing chilling injury to the fruit.

Table 3. Cooling conditions and final surface and mass-average (MA) temperatures for avocado cooling tests.

Test no.	Cooling temperature (°F)	Cooling medium	Air face velocity (fpm)	Initial fruit temp. (°F)	Time in cooler (min.)	Final temperature	
						Surface (°F)	MA (°F)
1	40	air	400	88	105	41-45	43-48
2	25	air	400	80	60	32-36	35-45
3	25	air	400	80	45	33-43	41-53
4	40	air	400	82	105	40-41	47-50
5	34	water	---	83	45	34-35	37-40
6	33	water	---	80	45	33-34	40-45
7	33	water	---	80	3days	33	33
8	25	air	100	90	90	34-48	41-54
9	0	air	100	95	40	32-53*	55-70
10	30	air	100	90	96	39-41	42-45
11	20	air	100	90	77	32-36	38-42
12	40	air	100	90	150	43-45	44-47
13	17	air	20	90	144	32-33	34-49
14	47	water	---	90	165	47	47
15	33	water	---	90	33	33.5	36
16	20	air	20	90	108	43	47
17	20	air	100	90	60	42	47
18	40	air	100	90	132	46	48
19	30	air	100	90	78	41	47
20	33	water	---	90	30	35	42
21	20	air	100	90	57	39	47
22	32	air	100	90	81	43	47
23	32	air	400	90	50	39	47
24	32	water	---	90	33	33	44

* The surface temperature of one of the smaller fruit in this test reached 32°F before the mass-average temperatures were adequately reduced. Therefore, the test was stopped at this point so that possible freeze damage would be avoided.

Literature Cited

1. Baird, C. D., J. J. Gaffney and D. T. Kinard. 1975. Research facility for forced-air precooling of fruits and vegetables. *ASAE Trans.* 18(2): 376-379.
2. Campbell, C. W. and T. T. Hatton, Jr. 1959. Chilling injury in Pollock avocados during cold storage. *Proc. Florida State Hort. Soc.* 72: 337-338.
3. Hatton, T. T., Jr., W. F. Reeder and C. W. Campbell, 1965. Ripening and storage of Florida avocados. *USDA, Ag. Res. Serv. MRR No. 697.* 13 p.
4. Lynch, S. J. and A. H. Stahl. 1939. Studies in the cold storage of avocados. *Proc. Fla. State Hort. Soc.* 52: 79-81.
5. Mustard, M. J. 1952. Effect of cold storage on some Florida avocados. *Proc. Fla. State Hort. Soc.* 65: 180-186.
6. Smith, R. E. and A. H. Bennett. 1965. Mass-average temperature of fruits and

vegetables during transient cooling. *ASAE Trans.* 8(2): 249-252, 255.

7. Smoot, J. J., L. G. Houck and H. B. Johnson. 1971. Market diseases of citrus and other subtropical fruits. *USDA, Ag. Res. Serv. Ag. Handbook No. 398.* 115 p.

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