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COMPARISON OF COOLING AND PACKAGING METHODS TO EXTEND THE POSTHARVEST LIFE OF OKRA

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Abstract. **Postharvest life of fresh okra (*Abelmoschus esculentus* L.) is limited to about 10 days storage at 7 to 10C (45 to 50F) and 90% relative humidity due to loss of chlorophyll and moisture, and increased toughness and decay. Storage at temperatures below this range has been reported to induce chilling injury. A series of five tests were conducted to determine the effects of rapid cooling methods, chlorinated cooling water and high relative-humidity packaging on postharvest quality of okra. The same day of harvest, okra pods ('Clemson Spineless') were cooled either by forced-air cooling (FA) or by hydrocooling (HY +/- chlorinated cooling water). After cooling pods were stored on trays or in rigid, vented containers (clamshells) fitted with absorbent bottom pads. Trays were either wrapped with plastic film (+/- perforations) or left unwrapped. Okra were stored from 0C (32F) to 30C (86F) for up to 14 d. Okra stored for 6 or 9d @ 8C (46F) + 1d @20C (68F) developed small brown-black discolorations at contact points, particularly with HY/wrapped treatments. Chilling injury symptoms were apparent when stored at 0C.There was less weight loss for okra stored in clamshells and perforated, wrapped trays than on unwrapped trays. Pods toughened during 7 d storage, increasing in shear force by about 50% or 100% when stored in clamshells or unwrapped trays, respectively. Surface color became more yellow (lower hue angle) and less intense (lower chroma value) for okra with all treatments. HY with 100 ppm free chlorine was usually injurious. Decay was most prevalent in wrapped treatments. The best appearance resulted from FA and storage in clamshell containers following 7d@10C + 1d@20C (68F).**

Okra is considered a minor vegetable crop in the United States and is grown primarily in the southern states. Florida shipped approximately 51,900 hundredweight out-of-state during the 1994-95 season, with a significant amount from Dade County (Geuder and Pugh, 1996). Okra is also processed into several products. Since it is harvested as an immature fruit, okra has a short postharvest life of about 10 days when stored at 7 to 10C (45 to 50F) and 90% relative humidity (Hardenburg, et al., 1986). It is quite sensitive to bruising, desiccation, loss of chlorophyll, chilling injury, loss in tenderness (increased toughness) and decay during postharvest handling. This extreme perishability has led investigators to determine the potential of storage in controlled atmosphere, 5% O_2/10% CO_2 (Baxter and Waters, 1990), and modified atmosphere in high-density polyethylene bags (Perkins-Veazie and Collins, 1992).

Rapid cooling plays an important role in extending postharvest quality of fresh produce, although little information has been reported for okra. Forced-air cooling is employed to some extent, however, if compatible with okra, hydrocooling might be a superior cooling method, since it is faster, rehydrating and has potential to aid in sanitizing fruit surfaces with the addition of chlorine (Ferreira, et al., 1995). Chlorinated water has also been reported to reduce incidence of browning at cut surfaces of potato and apple (Brecht, et al., 1993).

Maintaining high relative humidity (RH) through the use of plastic wraps has allowed some chilling-sensitive crops to be stored at lower temperatures without appearance of chilling injury symptoms (Cohen, et al., 1990.). High RH could further extend the postharvest life of okra should it have the same effect. Rigid, polyethylene containers (clamshells) have increased in usage for a number of crops as newer configurations become available for consumer packages. The vented design promotes maintenance of higher relative humidity for the product, while minimizing condensing conditions, and provides protection during handling and shipping.

The objectives of this work were to determine the effects of rapid cooling (forced-air cooling and hydrocooling), addition of chlorine to hydrocooling water and high relative-humidity packaging on the postharvest quality of okra.

Materials and Methods

A series of tests were conducted from June to August in 1995 and 1996. 'Clemson Spineless' was grown at the Horticultural Research Unit, University of Florida, Gainesville, using commercially accepted practices. Pods approximately 4 inches (10 cm) in length were clipped and placed into shallow containers to minimize mechanical injury, and immediately transported to the laboratory. All experiments were set up on the day of harvest. Blemish-free pods were randomized into respective treatments.

For all tests, forced-air cooling was accomplished by laying individual pods on styrofoam trays at 8C (46F) with moderate air movement until 7/8 of the field heat was removed ("7/8 Cooling"; about 45 min). Hydrocooling consisted of immersion of the pods in agitated, iced tap water until "7/8 Cooling" was achieved (about 8 min). Following hydrocooling, the pods were carefully blotted dry with clean absorbent towels prior to arrangement on food-grade absorbent pads (Pink MB, Kimberly-Clark, Rosswell, GA) which were placed on the storage tray or in the rigid container.

Fruit quality (surface color, moisture loss, appearance) was determined at regular intervals during storage. Surface color (L*, a*, b*) was measured at the equator of individual fruits by a chromameter equipped with a 1 cm port (Minolta, CR-200, Ramsey, NJ). Hue angle and chroma values were calculated from a* and b* values. Maximum shear force was determined with a single blade attached to a Universal Testing Machine (Instron, Model 1132, Atlanta, GA), fitted with a 10 kg load cell, and set at 10 cm/min crosshead and chart speeds. Weight loss was determined throughout storage and appearance was subjectively rated (% fruit exhibiting surface browning, pitting, decay).

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The following tests were performed in 1995 (#1-3) and 1996 (#4, 5):

Test 1. Compare cooling methods and +/- plastic wrap. Okra (n = 10 pods) were either forced-air cooled or hydrocooled (non-chlorinated water) and stored +/- non-perforated plastic wrap for 5 d @ 8C (46F) + 2 d @ 20C (68F), 7 d @ 20C or 5 d @ 30C (86F).

Test 2. Compare cooling methods, plastic wrap +/- perforations and hydrocooling +/-chlorine. Okra pods (n = 10) were forced-air cooled or hydrocooled (+/- 100 ppm free chlorine; pH about 7.0) and stored with plastic wrap +/- 5 pinholes/tray for 7 d @ 8C + 2 d @ 20C or 9 d @ 20C.

Test 3. Document chilling injury symptoms. Pods (n = 10) were forced-air cooled and stored unwrapped on trays at 0C (32F), 8C, 12C (55F) or 20C. Following 5 d storage, the 0C, 8C and 12C treatments were transferred for 2 d @ 20C to permit development of chilling any injury symptoms.

Test 4. Compare length of storage and +/- film wrap on development of chilling injury symptoms. Okra (n = 15) was forced-air cooled on trays and stored +/- wrap at 8C for 3, 6 or 9 d plus 1 d @ 20C.

Test 5. Compare cooling methods and storage on unwrapped trays or in clamshells on quality after 7 and 14 d. Okra (n=15) was forced-air cooled on trays or hydrocooled (+ chlorine) and stored on an unwrapped tray or in a vented clamshell approximately 13 cm × 13 cm × 7 cm (H) (Ultra-Pac, Minneapolis, MN) for 7 or 14 d @ 10C (50F) plus 1 d @ 20C.

Results and Discussion

Test 1. Unwrapped okra lost significantly more weight than wrapped okra (Table 1). Weight loss also was greater as storage temperature increased, regardless of cooling method. For the forced-air (FA) cooled treatment, pods stored on wrapped trays at 8C lost only 2.5% weight, compared to 13.0% for those that were stored unwrapped. Okra stored on wrapped and unwrapped trays at 20C lost 6.7% and 26.0% weight, respectively. Weight loss of wrapped okra was comparable for both cooling methods at the same storage temperature, whereas, hydrocooled (HY) pods which were stored unwrapped lost more weight at 8C (20.0%) and 30C (49.6%) than HY/unwrapped pods. The weight gain incurred during HY was reflected in a higher weight loss for HY/unwrapped okra during storage.

Pod toughness, as measured by shear force, increased significantly with increasing storage temperature for all treatments, although for a given storage temperature, neither cooling method nor relative humidity (+/- wrap) significantly affected shear force (Table 2). Wrapped and unwrapped okra stored at 8C and 20C developed numerous brown/black lesions on the pod surfaces; these were not present on pods stored at 30C (data not shown). The cause of these lesions was not determined in this test. Decay was most noticeable at 30C storage, particularly mold mycelia (data not shown). Surface color appeared more yellow for unwrapped pods stored at 30C than for those from other treatments (data not shown).

Table 1. Weight loss following cooling and storage for wrapped and unwrapped okra.

Cooling treatment	Storage temperature (C)[z]		
	8C	20C	30C
	Weight loss (%)		
Forced-air (wrapped)	2.5 c[y]	6.7 b	22.8 c
Forced-air (unwrapped)	13.0 b	26.0 a	40.6 b
Hydrocooled (wrapped)	1.3 c	5.5 b	22.5 c
Hydrocooled (unwrapped)	20.0 a	26.0 a	49.6 a

[z]8C: 5 days + 2 days @ 20; 20C: 7 days; 30C: 5 days; (n=10).
[y]Mean separation within each column by Duncan's multiple range test, P=0.05.

Table 2. Shear force (N) following cooling and storage for wrapped and unwrapped okra.

Cooling treatment	Storage temperature (C)[z]		
	8	20	30
Forced-air (wrapped)	75.9 b[y]	101.2 ab	119.5 a
Forced-air (unwrapped)	73.9 b	101.6 a	110.0 a
Hydrocooled (wrapped)	70.9 b	106.5 a	116.5 a
Hydrocooled (unwrapped)	80.6 b	99.1 b	127.5 a

[z]8C: 5 days + 2 days @ 20; 20C: 7 days; 30C: 5 days; (n=10).
[y]Mean separation within each row by Duncan's multiple range test, P=0.05.

It was concluded from this test that wrapping was beneficial in reducing weight loss during storage but it appeared to aggravate the development of small lesions on the pods. There were no significant differences in overall okra quality due to cooling method.

Test 2. Cooling by FA and storage in perforated film wrap at 8C resulted in the best overall pod quality (as measured by color, tenderness, weight loss, appearance) of all treatments (data not shown). However, the addition of chlorine to hydrocooling water did not improve quality. Following storage at 8C, there was actually less total decay for okra HY with non-chlorinated water (0%) than with chlorinated water or by FA (Fig. 1). While not confirmed in this test, the pubescence on pod surfaces may have been injured by the 100-ppm chlorinated hydrocooling water resulting in lesions. Okra cooled by FA or HY + chlorine, wrapped with perforated film and stored at 8C had less decay than that which was wrapped without perforations. The apparently lower relative humidity in the trays wrapped with the perforated film may have provided less favorable conditions for the growth of decay microorganisms than those wrapped with non-perforated film.

Test 3. Okra stored at 0C for 5 d + 2 d @ 20C had characteristic chilling-injury symptoms - black, sunken lesions and secondary decay as described by Fontenot, et al. (1987). These symptoms were not apparent on pods stored at 8, 12 or 20C. Surface color of okra after storage at 0C was darker, less green and duller than that of pods from the other treatments, as indicated by lower L* values, hue angles and chroma values (Table 3). Those pods stored at 8C, 12C and 20C retained color values similar to initial values. Weight loss was lowest for okra stored at 8C (12%), while pods stored at 0C, 12C and 20C lost 21%, 16% and 20% of the original weight, respectively. The small, black lesions which were observed on okra stored at 8C in Tests 1 and 2 were not observed on okra stored at 8C in this test. Apparently, this disorder was not a result of chilling injury but, rather, a consequence of the high RH environment and the presence of free moisture where the okra was in contact with other surfaces for extended periods of time.

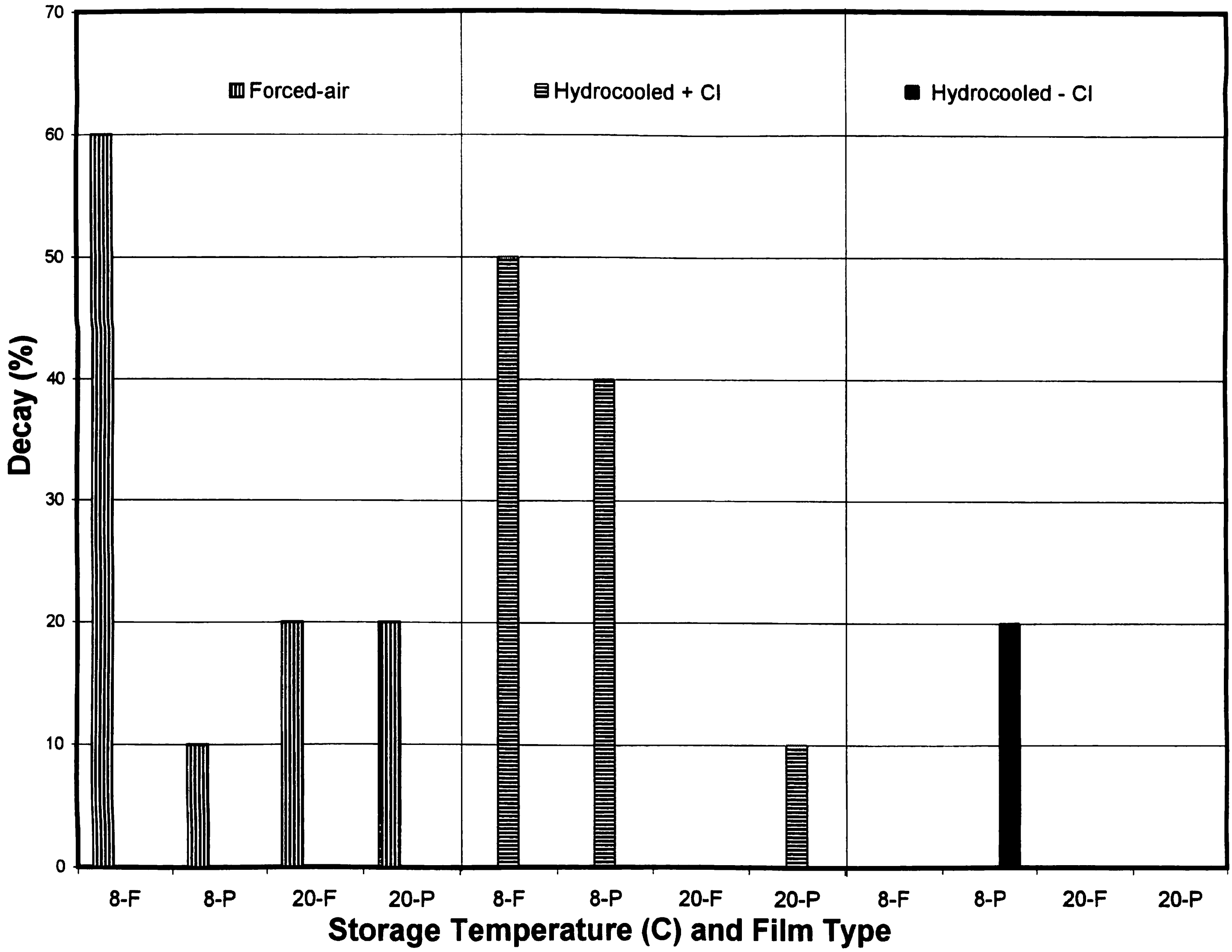

Figure 1. Incidence of decay for okra following forced-air cooling or hydrocooling (+/-chlorine), wrapping with non-perforated film (F) or perforated film (P), and storage for 7 d @ 8C + 2 d @ 20C, or 9 d @ 20C.

Test 4. Beginning with 3 d storage and continuing until 9 d, FA/unwrapped okra stored at 8C were noticeably darker, duller and tougher than those which were wrapped (Tables 4a,b). After 9 d, L* and chroma values for FA/unwrapped okra were much lower (42.1 and 26.5, respectively) than those for FA/wrapped okra (46.7 and 31.3, respectively). Likewise, shear force increased by more than 64% to 85.1 N for unwrapped okra following 9 d storage, while wrapped okra increased in toughness by only 18% in the same storage regime. Surface color and shear-force data indicate the importance of minimizing moisture loss during postharvest storage of okra, while avoiding excessively high RH within the wrapped tray.

Test 5. Following extended storage to 14 d at 10C and 88% RH plus 1 d at 20C, FA and HY okra held in clamshell-type containers was more tender than that stored on unwrapped trays (Tables 5a,b). Okra which was HY/unwrapped, increased in shear force by almost 100% to 95.2 N after 7 d stor-

Table 3. Surface color and weight loss for unwrapped okra following 7 days at selected temperatures (forced-air cooled).

		Storage temperature (C)			
Surface color	Initial	0	8	12	20
L*-value	53.2	42.2	51.1	51.7	54.6
Hue angle	122.0	111.5	121.2	121.3	121.5
Chroma	39.6	22.9	36.4	37.1	39.0
Weight loss (%)	—	21.4	11.8	15.5	20.2

(n=10)

Table 4a. Surface color and shear force for unwrapped okra stored for 3, 6, or 9 days at 8C (forced-air cooled).

	Storage length (days)[z]			
Surface color	0	3	6	9
L*-value	50.2	47.7	47.9	42.1
Hue angle	124.4	124.7	123.9	122.1
Chroma	38.2	32.6	33.2	26.5
Shear force (N)	51.8	62.1	76.9	85.1

[z]Days stored @ 8C + 1 d @ 20C; (n=10).

Table 4b. Surface color and shear force for wrapped okra stored for 3, 6, or 9 days at 8C (forced-air cooled).

	Storage length (days)[z]			
Surface color	0	3	6	9
L*-value	50.2	48.5	48.2	46.7
Hue angle	124.4	124.6	123.1	120.2
Chroma	38.2	36.6	37.6	31.3
Shear force (N)	51.8	46.1	61.7	61.3

[z]Days stored @ 8C + 1 d @ 20C; (n=10).

age at 10C (Table 5a); those which were FA/unwrapped required only 78.7 N after 7 d storage, but by 14 d required 91.7 N. Pods cooled by either HY or FA and stored in clamshells were more tender than the unwrapped treatments following 14 d storage, having shear-force values approximately 15 N lower (Table 5b). There was no increase in toughness between 7 and 14 d storage when stored in clamshells. Shear-force values for FA and HY okra stored in clamshells were similar to those obtained in Test 2 for wrapped and unwrapped okra cooled by these same methods (71 to 81 N) following 5 d @ 8C + 2 d @ 20C (Table 2), and to those from Test 4 for FA/wrapped okra (61 N) following 9 d at 8C + 1 d at 20C (Table 4). Color data indicated that FA and HY okra stored in clamshells for 14 d were slightly more yellow than those stored on the unwrapped trays.

Okra, cv. Clemson Spineless, appears to be susceptible to small, black lesions on surfaces after about 6 d storage at 8C, particularly when RH approaches 100%. Perforations in the plastic-film wrap reduced discoloration and decay. Pods which were forced-air cooled had better appearance following storage than those which were hydrocooled. The addition of 100 ppm free chlorine to hydrocooling water generally increased the incidence of necrotic lesions during subsequent storage. Forced-air cooled okra stored in vented clamshell containers had acceptable appearance, was more tender and lost less weight following 7 d at 10C + 1 d at 20C; storage at 8C in clamshells should further increase postharvest life. The role of mechanical injury on surface browning and weight loss should be addressed.

Table 5a. Surface color and shear force for okra as affected by cooling method, container type and storage length.

	Unwrapped tray					
		Hydrocooled			Forced-air cooled	
Surface color	Initial	7 days[z]	14 days	Initial	7 days	14 days
L*-value	50.8	50.1	51.0	50.8	51.3	52.9
Hue angle	123.5	120.7	118.2	123.5	122.2	118.6
Chroma	38.2	35.4	35.1	38.2	37.1	38.0
Shear force (N)	50.5	95.2	92.3	50.5	78.7	91.7

[z]Stored 7 or 14 d @ 10C and 88% R.H. + 1 d @ 20C; (n=15).

Table 5b. Surface color and shear force for okra as affected by cooling method, container type and storage length.

	Clamshell					
		Hydrocooled			Forced-air cooled	
Surface color	Initial	7 days[z]	14 days	Initial	7 days	14 days
L*-value	50.8	51.9	51.9	50.8	52.7	52.3
Hue angle	123.5	121.6	116.9	123.5	121.8	116.3
Chroma	38.2	37.7	36.1	38.2	39.3	36.4
Shear force (N)	50.5	79.4	77.1	50.5	78.1	75.1

[z]Stored 7 or 14 d @ 10C and 88% R.H. + 1 d @ 20C; (n=15).

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