Greenberg, J., R. Goren, and J. Riov. 1975. The role of cellulase and polygalacturonase in abscission of young and mature Shamouti orange fruits. Physiol. Plant. 34:1-7.
Huberman, M. and R. Goren. 1979. Exo- and endo-cellular cellulase and polygalacturonase in abscission zones of developing orange fruits. Physiol. Plant. 45:189-196.
Kalaitzis, P., S. M. Koehler, and M. L. Tucker. 1995. Cloning of a tomato polygalacturonase expressed in abscission. Plant Molec. Biol. 28:647-656.
Koehler, D. E., L. N. Lewis, L. M. Shannon, and M. L. Durbin. 1981. Purification of a cellulase from kidney bean abscission zones. Phytochemistry 20:409-412.
Kossuth, S. V. and R. H. Biggs. 1977. Cellulase isoenzymes in citrus. Proc. Int. Soc. Citriculture 2:683-686.
McKendree W., C. J. Nairn, and M. Bauscher. 1995. Differential display from plant leaves by oligo dT magnetic bead mRNA isolation and hot air PCR. Biotechniques 19:715-719.
Nelson, N. 1944. A photometric adaptation of the Somogyi method for the detection of glucose. J. Biol. Chem. 153:375-380.
Riov, J. 1974. A polygalacturonase from citrus leaf explants. Role in abscission. Plant Physiol. 53:312-316.
Sambrook, J., E. F. Fritsch, and T. Maniatis. 1989. Molecular Cloning: A Laboratory Manual. Second edition. Cold Spring Harbor Laboratory Press, New York.
Sexton, R. and J. A. Roberts. 1982. Cell biology of abscission. Ann. Rev. Plant Physiol. 33:133-162.
Taylor, J. E., S. A. Coupe, S. Picton, and J. A. Roberts. 1994. Characterization and accumulation of an mRNA encoding an abscission-related ß-1,4-glucanase from leaflets of *Sambucus nigra.* Plant Molec. Biol. 24:961-964.
Tonutti, P., L. G. Cass, and R. E. Christoffersen. 1995. The expression of cellulase gene family members during induced avocado fruit abscission and ripening. Plant Cell Environ. 18:709-713.
Tucker, M. L., R. Sexton, E. delCampillo, and L. N. Lewis. 1988. Bean abscission cellulase: Characterization of a cDNA clone and regulation of gene expression by ethylene and auxin. Plant Physiol. 88:1257-1262.
Whitney, J. D. 1995. A review of citrus harvesting in Florida. Trans. of the 1995 Citrus Engineering Conference, Florida Section. 41:22-59.
Whitney, J. D. and R. C. Harrell. 1989. Status of citrus harvesting in Florida. J. Agric. Eng. Res. 42:285-299.

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COOLING PERFORMANCE EVALUATION OF STRAWBERRY CONTAINERS

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Abstract. **The decision by Florida strawberry growers to adopt the 40 × 48 inch (100 × 120 cm) MUM (Modularization, Unitization, and Metrification) shipping pallet required that they adopt new flats for these pallets. In order to help select the best packaging system, the growers desired cooling performance evaluations of different corrugated flat designs (several base dimension and vent arrangements), as well as comparisons of strawberries cooled in pint mesh baskets, and pint and quart clamshells. Commercial forced-air cooling tests were conducted to compare various package configurations and the results are presented. Strawberry weight loss and changes in the humidity of the cooling room air during forced-air cooling are also presented.**

During the 1994-1995 season, Florida sold 14 million flats of strawberries with an average price per flat of $8.47 and a total crop value in excess of $118 million (Fla. Dept. Agr. 1996). These figures are based on the standard 13 × 19.5 inch Florida flat packed with square injection-molded plastic mesh pint baskets filled with strawberries with an approximate total weight of 5.4 kg (12 lb). The Florida flats are shipped on 37.5 × 39 inch, 2-way pallets with six flats per layer and 16 flats high. Future reporting will have to account for the remarkable increase in strawberry packaging options that has occurred during the last two years.

Three years ago the national fresh produce industry adopted the 40 × 48 inch (100 × 120 cm MUM) 4-way pallet as the standard shipping pallet. The Florida Strawberry Growers Association, a progressive group of growers who continually explore emerging technologies and techniques to remain competitive, made the commitment to adopt the standard pallet. In response, strawberries are now being packed in new flats because the original Florida flat does not fit squarely onto the 40 × 48 pallet. Two flat options for the 40 × 48 pallet are currently available - the 12 × 20 inch and the 16 × 20 inch (Consumer) flats.

In addition to pallet and flat changes, individual containers are changing from the mesh baskets to clear, thermoformed plastic clamshell containers introduced a few years ago by California shippers. After some initial resistance, the clamshell containers have been received positively all the way along the line from field pickers to produce retailers and final consumers. Berries in clamshells do not need repacking and are handled less than berries in baskets. The containers can also be turned over for easy quality checking.

The past strawberry season was unique for the large number of package configurations used to ship berries or which received serious consideration for use with strawberries. The increasing popularity of clamshell baskets and the change to the 40 × 48 pallet have resulted in a large number of potential combinations of flats and baskets. This situation will inevitably result in a relatively few packaging systems being adopted as "standards", while other systems will fall by the wayside. The sheer number of options can cause aggravation in the field, the packinghouse, and the market. Cady (1995) compared berry capacity and materials costs of nine types of packaging and reported that the most economical packaging choice will vary with the cost of the materials and the market price. In ad-

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dition, future use of the Florida flat with mesh baskets was predicted to be more limited due to the standardized pallet and because fewer berries are sold per flat when berries are packaged in clamshell containers, resulting in greater relative yield. This benefit of increased number of flats per acre is, however, largely offset by the greater container cost.

In addition to the economic factors, another consideration in the selection of a strawberry packaging system that is very important, given the extreme perishability of the berries, is how quickly and efficiently the strawberries can be cooled in a particular packaging system.

Strawberries are currently field packed into containers in the flats, then palletized and transported for precooling at a central forced-air cooling facility. Two adjacent rows of pallets form a tunnel when canvas is placed over the space between the rows of pallets (Fig. 1). Fan(s) pull air from one end of the tunnel producing cooling as refrigerated air is pulled through the containers of product.

Commercial forced-air precooling (Mitchell, *et al.*, 1972; Parsons, *et al.*, 1970; Kader, *et al.*, 1985) is an important postharvest procedure in Florida for rapid cooling and maintaining quality of strawberries in addition to several vegetable crops and cut flowers. In Florida, strawberries have been precooled using forced-air for nearly 20 years, with many state-of-art cooling systems placed in service in the last 5 years.

Although the clamshell package is popular with consumers and has brought higher returns to growers, a common perception within the industry is that clamshells can extend the time required for forced-air cooling by more than 40%. Singh (1991) conducted early research on the clamshells and reported an overall 30-40% better cooling performance. Recent work by Emond *et al.* (1995) reported berries in clamshells forced-air cooled in 30-51% less time compared to mesh baskets. Talbot and Baird (1991) and Talbot *et al.* (1993) worked extensively with 1-1/9 bu and MUM pepper containers forced-air cooled on 40 × 48 pallets and reported 40% increased cooling times when the openings in the pallets were not blocked to prevent cooling air by-pass. Reliable information on cooling rates and uniformity of cooling require that different packaging systems be tested side-by-side in commercial cooling facilities with extensive instrumentation of the pallets using thermocouple temperature probes and datalogging equipment.

This study was initiated with the objectives to evaluate cooling performance of several packaging configurations using pint mesh baskets and pint & quart clamshells in standard, 12 × 20, and 16 × 20 corrugated flats, with various flat vent openings. In addition, as a result of several inquiries from Florida strawberry grower/shippers concerning product moisture loss during forced-air cooling, weight loss of the strawberries and the humidity of cooling room air during forced-air cooling were measured.

Materials and Methods

Table 1 lists the test numbers and combinations of containers, flats and pallets evaluated. The pulp temperature measurements were accomplished using 64, 24-gauge thermocouples and a CR10 datalogger (Campbell Scientific, Inc.) with two multiplexers. For each pallet tested, one layer of flats approximately mid height (Figs. 2-4) was instrumented with 30 thermocouples inserted approximately 1.3 cm (0.5 inch) into the calyx end of approximately the same size and shape strawberries, which were placed at strategic locations within the flats in pint or quart containers, one strawberry per container. The thermocouples were placed so that in addition to the average temperature measurement for the pallet layer, the temperature gradient in the direction of airflow could be determined (Fig. 1). One thermocouple per pallet was used to measure the air entering the pallet and another was used to measure the temperature of the air leaving the pallet.

To determine moisture loss during forced-air cooling, each container selected for instrumentation with a thermocouple was marked and weighed with an electronic scale before and after cooling.

To establish the change in moisture content or relative humidity of the cooling air in the forced-air cooler, an aspirated wet bulb/dry bulb thermometer was utilized for four tests.

Table 1. Summary of strawberry cooling tests.

Test no./container/flat/pallet type/ cooling width/% vent opening	Average air temp. (°F)	Initial pulp temp. (°F)	1/2-cool time (hr)	7/8-cool time (hr)	Weight loss (%)
1/mesh pint/std. flat/ 37.5 × 39/39 in/15.6%	31.1	70.7	0.42	0.87 (est.)	1.25
1/clam. pint/std. flat/ 37.5 × 39/39 in/15.6%	38.2	71.8	0.47	0.90	0.56
2/clam quart/16 × 20 vented/ 40 × 48/48 in/21.0%	31.3	76.0	0.52	1.04	0.63
2/clam pint/16 × 20 vented/ 40 × 48/48 in/21.0%	31.3	76.3	0.41	0.97	0.47
3/mesh pint/std. flat/ 37.5 × 39/39 in/15.6%	38.4	68.8	0.50	0.82	NA
4/clam quart/16 × 20 vert. vent. w/o divider/40 × 48/40 in/8.0%	36.8	67.9	0.36	0.83	1.06
5/clam quart/16 × 20 w/o vent/ 40 × 48/48 in/18.0%	35.2	68.6	0.44	1.20	0.90
5/clam pint/16 × 20 w/o vent/ 40 × 48/48 in/18.0%	36.6	70.7	0.36	1.10	0.86
6/mesh pint/12 × 20/ 40 × 48/48 in/15.7%	37.1	68.7	0.41	0.85	NA
7/mesh pint/12 × 20 bottom vent untaped/40 × 48/48 in/15.7%	39.9	75.0	0.35	0.80	NA
7/mesh pint/12 × 20 bottom vent taped/ 40 × 48/48 in/14.9%	40.0	78.0	0.36	0.85	NA

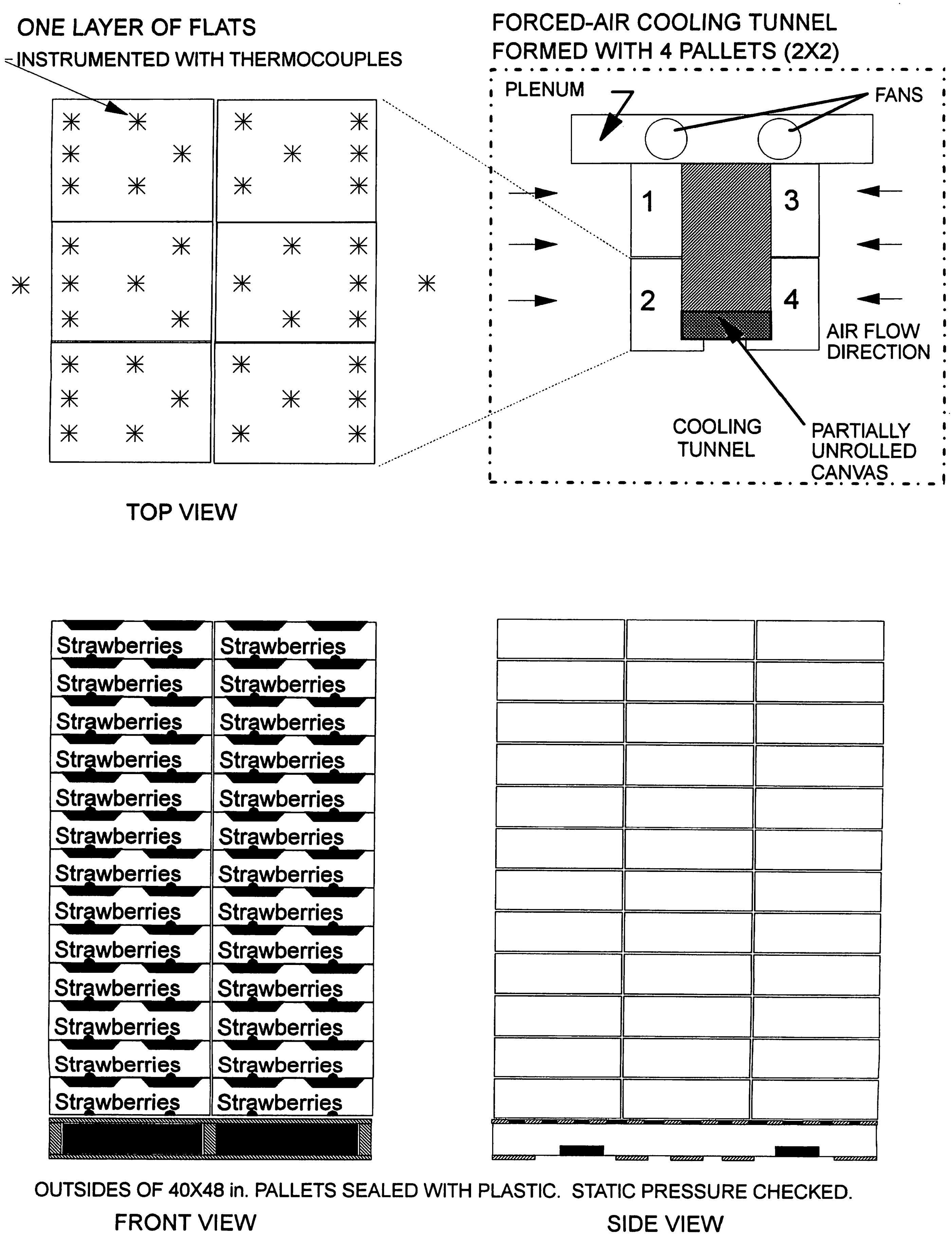

Figure 1. Comparative strawberry cooling test setup.

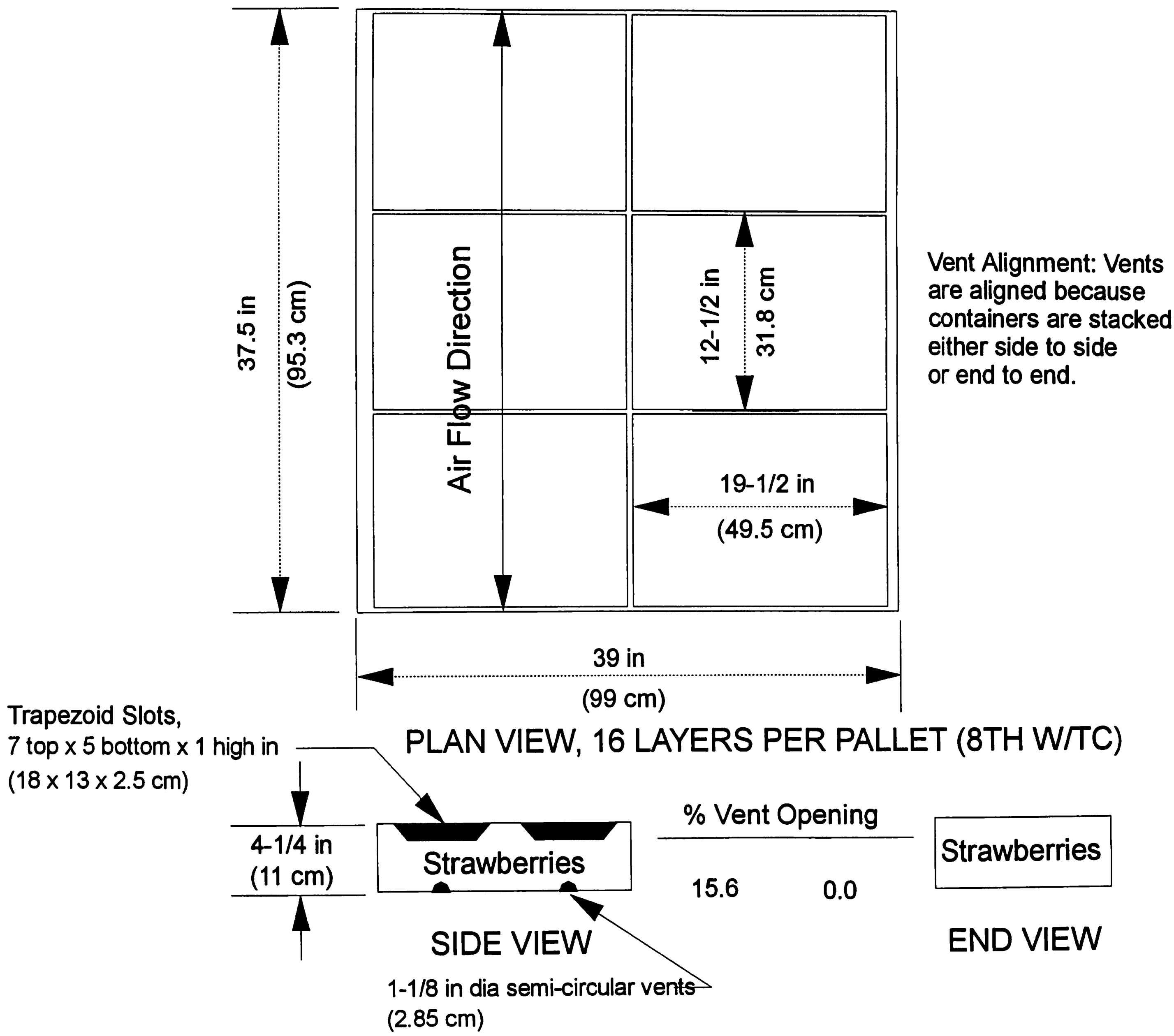

Figure 2. Standard or Florida strawberry flat on non-MUM pallet.

The test setup is illustrated by Fig. 1. All tests were conducted with a forced-air cooling tunnel of 4 pallets (2 x 2) on one of four identical cooling units. The principle of path of least resistance is a key physical relationship which requires that the openings in the pallets be blocked in order to prevent cooling air from bypassing (short circuiting) through the openings in the 4-way pallets, so that maximum air flow passes through the flat vents. For every test, 30 cm (12 inches) wide plastic film was used to block the openings in the pallet sides by covering the pallet sides along the entire perimeter of the tunnel.

The static pressure difference between the outside and inside of the tunnel was measured at the end of the tunnel opposite the fan, using a hand-held digital manometer. With the fan on, the static pressure was measured before and after the addition of plastic to the pallet sides along the perimeter of the cooling tunnel.

The carton vent dimensions were measured in order to calculate the percent vent open areas and verify percent opening greater than the recommended minimum 5% (Baird *et al.*, 1988).

All tests were conducted at a commercial cooling facility. The desired final cooling point for all tests was the 7/8th-cooling point. Efforts to avoid disruption of normal commercial operations and associated time factors required some modifications to the procedures. In some tests, the cooling facility personnel terminated the cooling before the desired goal. The tests were conducted in the late part of the season when seasonal volume and prices decline, which limited availability of particular package configurations. The initial berry temperatures varied depending on ambient conditions but were generally not very warm. During rainy weather, berries were not packed and during cool weather less cooling was required.

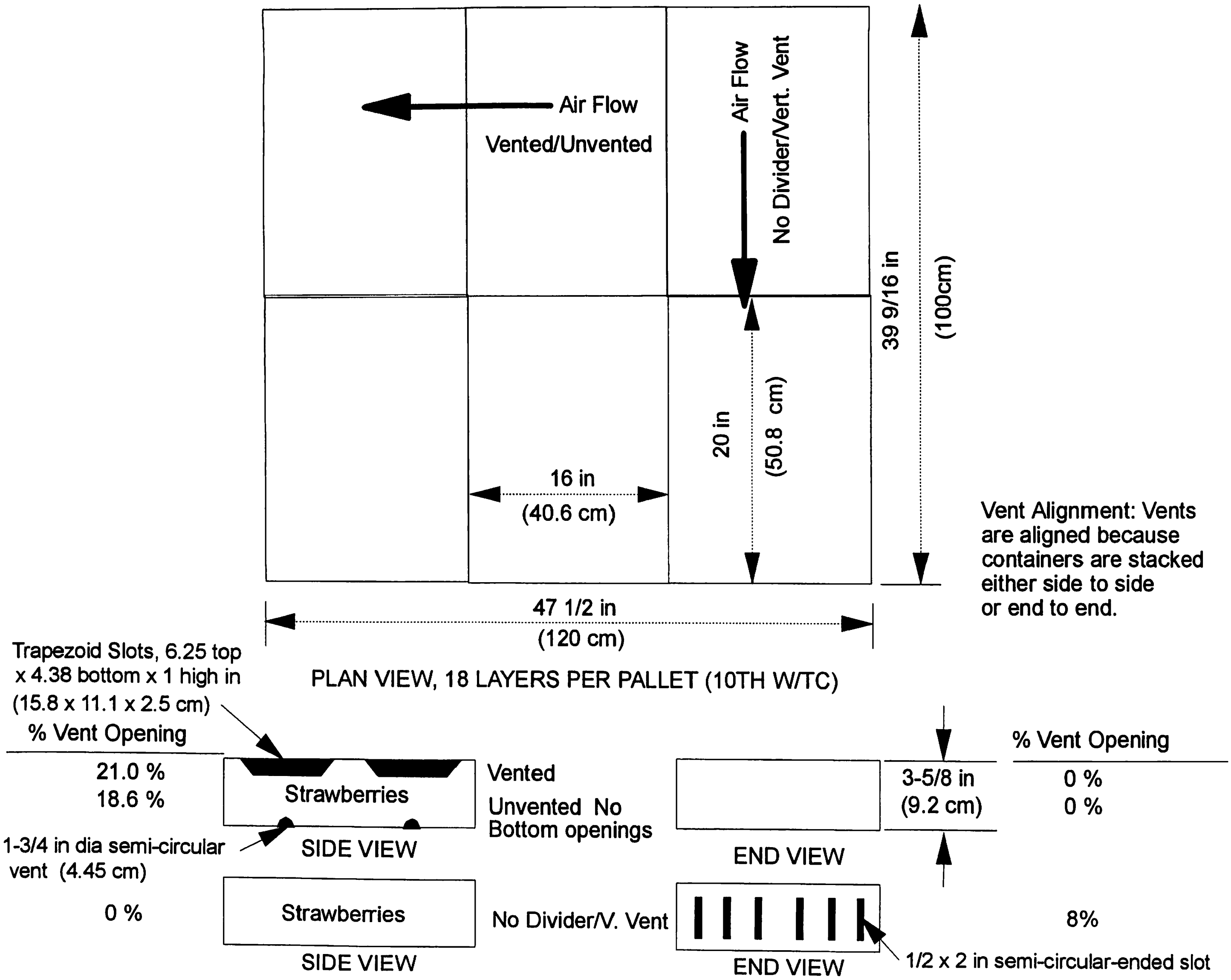

Figure 3. 16 × 20 inch strawberry flat on MUM pallet.

Results and Discussion

The flat dimensions, vent sizes and locations, % vent openings, configurations on the pallets, flat vent openings, layer of flats instrumented, and cooling air directions for the flats used are shown in Figs. 2-4. Vent openings aligned with the vents of adjacent flats in all tests.

The flat venting was not as critical with the mesh basket as with the pint or quart clamshells. The vents in the flat did not always align with the opening in the clamshells. For one flat and clamshell combination, the flat vents at the bottom of the side wall aligned with the space between adjacent clamshells. This allowed cooling air to move through this space from the outside to the inside of the pallet with little cooling air entering the clamshells.

Table 1 presents the cooling width, the percent vent opening, the cooling air temperature, and the initial berry pulp temperature for each test. For tests with a cooling width of 48 inches (120 cm), the 40 × 48 pallet was rotated 90 degrees. Therefore, an additional 8 inches (20.3 cm) of strawberries (9 inches or 22.9 cm when compared to the 37.5 × 39 pallet) was cooled for this configuration. This orientation can present other problems. Some coolers are not wide enough to accommodate 48 inch wide pallets. The full openings (Fig. 1) of the pallet will allow substantial cooling air bypass if not properly sealed, although the side openings can also allow significant bypass.

In addition, Table 1 provides comparative cooling performance (average pallet temperature) in terms of the 1/2 and 7/8th cooling times. The 1/2 cooling time is the time required to remove one half the difference between the initial pulp temperature and the cooling medium temperature. The 7/8th cooling time corresponds to removal of 7/8th of this initial temperature difference. From a quality perspective, 7/8th cooling is preferred.

When cooling rates for strawberries in standard flats with pint mesh baskets were compared to standard flats with pint clamshells (Tests 1 and 3), the 7/8th cooling time for the mesh baskets was slightly less than the clamshells due to the open structure of the mesh basket but certainly not 40% less. A probable explanation for the perception that clamshells require 40% longer cooling times is incomplete analysis of the

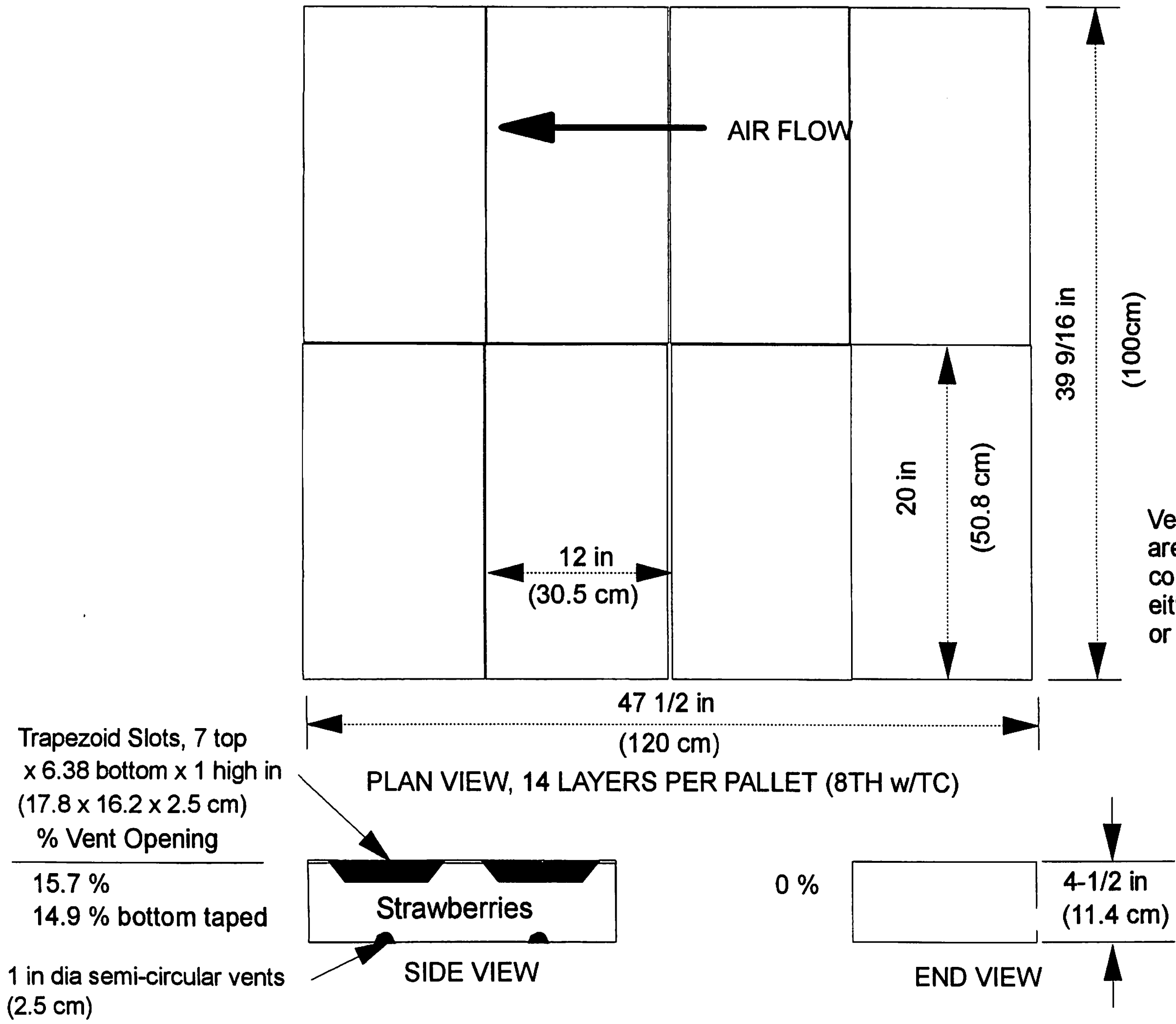

Figure 4. 12 × 20 inch strawberry flat on MUM pallet.

problem of increased cooling time. When cooling problems and increased cooling times were observed, the analyst was likely to work the problem by stepping back. By first assuming or neglecting the potential for air bypass or leakage through the 40 × 48 pallet openings, the first obvious potential problem was the new, plastic clamshells.

With the exception of the 12 × 20 flats, the width of cooling was directly related to the time for cooling. Cooling across the 40 inch width of the 40 × 48 pallet (cooling air perpendicular to the 48 inch side) appears to be advantageous from a cooling efficiency standpoint. In addition, loading the pallets in this orientation is more efficient, since the pallet does not require the 90 degree turn using stop and go forklift operation.

The 16 × 20 flats without dividers and with vertical slot openings (not trapezoidal vents common to most flats; Test 4) performed well compared to traditionally configured flats (Tests 2 and 5), indicating the potential for designing even faster cooling strawberry flats. Arifin and Chau (1988) reported that a similar flat design with six, 3.81 cm (1.5 inch)-diameter circular vent holes cooled significantly better than the standard flat. The circular vents provided a higher percent vent opening (13.5%) than the vertical slots (8%). The standard flat trapezoidal vents appear to allow air to pass through the pallet above rather than through the berries.

The results of the comparison of pint and quart clamshells in the 16 × 20 flats (Tests 2 and 5) indicate that berries cool slightly more rapidly in the pint clamshell than the quart clamshell. The vents in the clamshell, clamshell orientation in the flats, and alignment of the clamshell vents with the flat vent openings are all factors that need to be studied further. The work of Emond *et al.* (1995) could provide the best clamshell venting design.

Comparing Test 2 to Test 5 further illustrates that the 16 × 20 flats without additional vents cooled more rapidly than the flats with additional vent holes. The difference in venting consisted of the semi-circular vents at the bottom edge shown in Fig. 3 as well as several vent openings in the bottom of the flat. Some growers were led to believe by unknown sources that the vents in the bottom of the flats would increase cooling rates as a result of a "venturi effect". This unproven assumption supposed that, as air flowed horizontally through the trapezoidal vents above the berries packed in individual containers that a pressure difference would create a vertical air flow through the bottom of the flat and up through the berries. Our results show that, while these vertical vents may

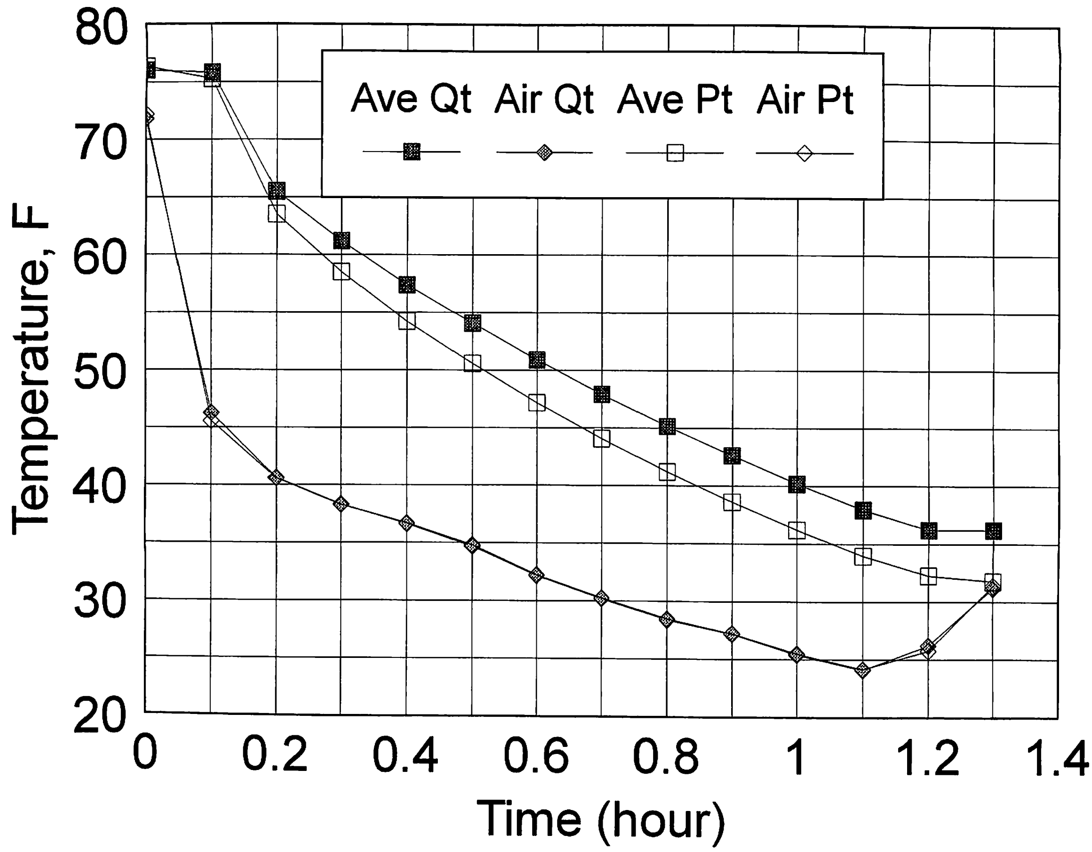

Figure 5. Comparative cooling curves for 16 × 20 flat and pint versus quart clamshells (Test 2).

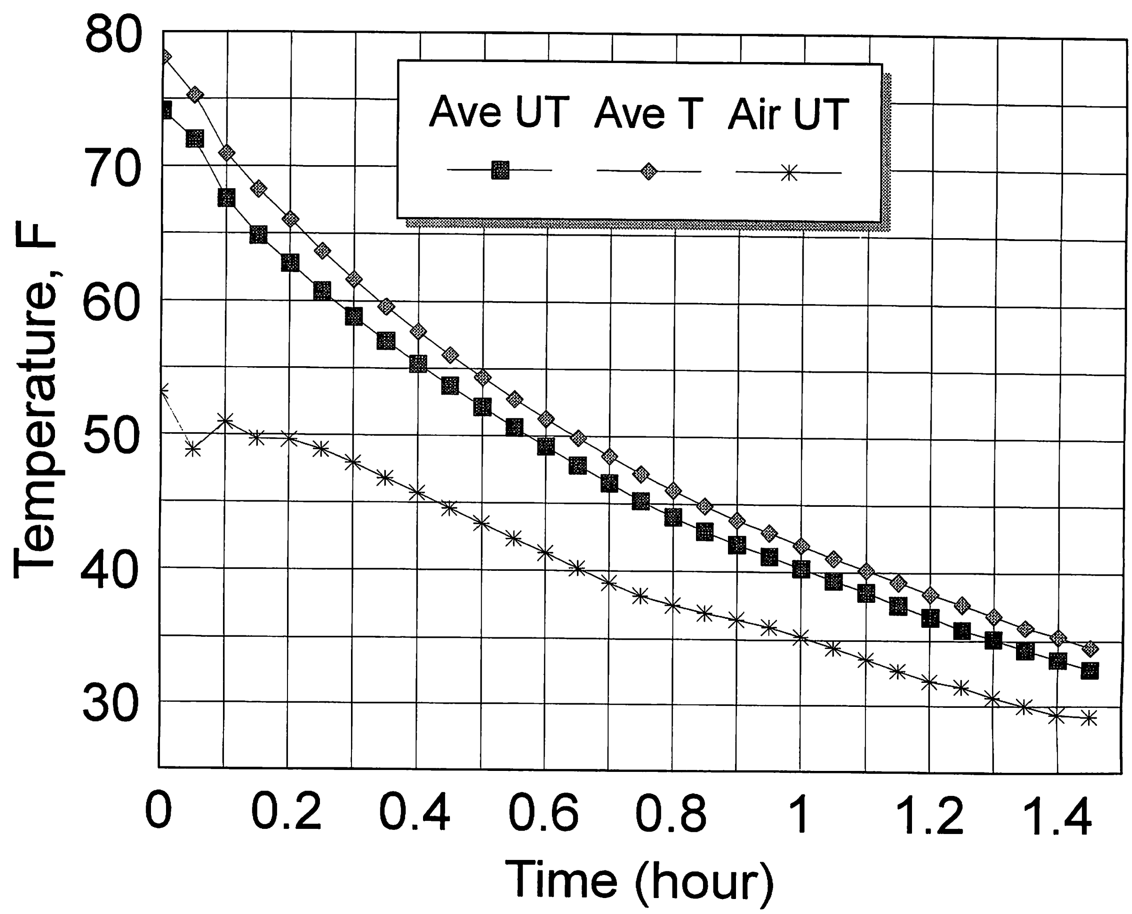

Figure 6. Comparative cooling curves for 12 × 20 flat and mesh pint with taped versus untaped vents (Test 7).

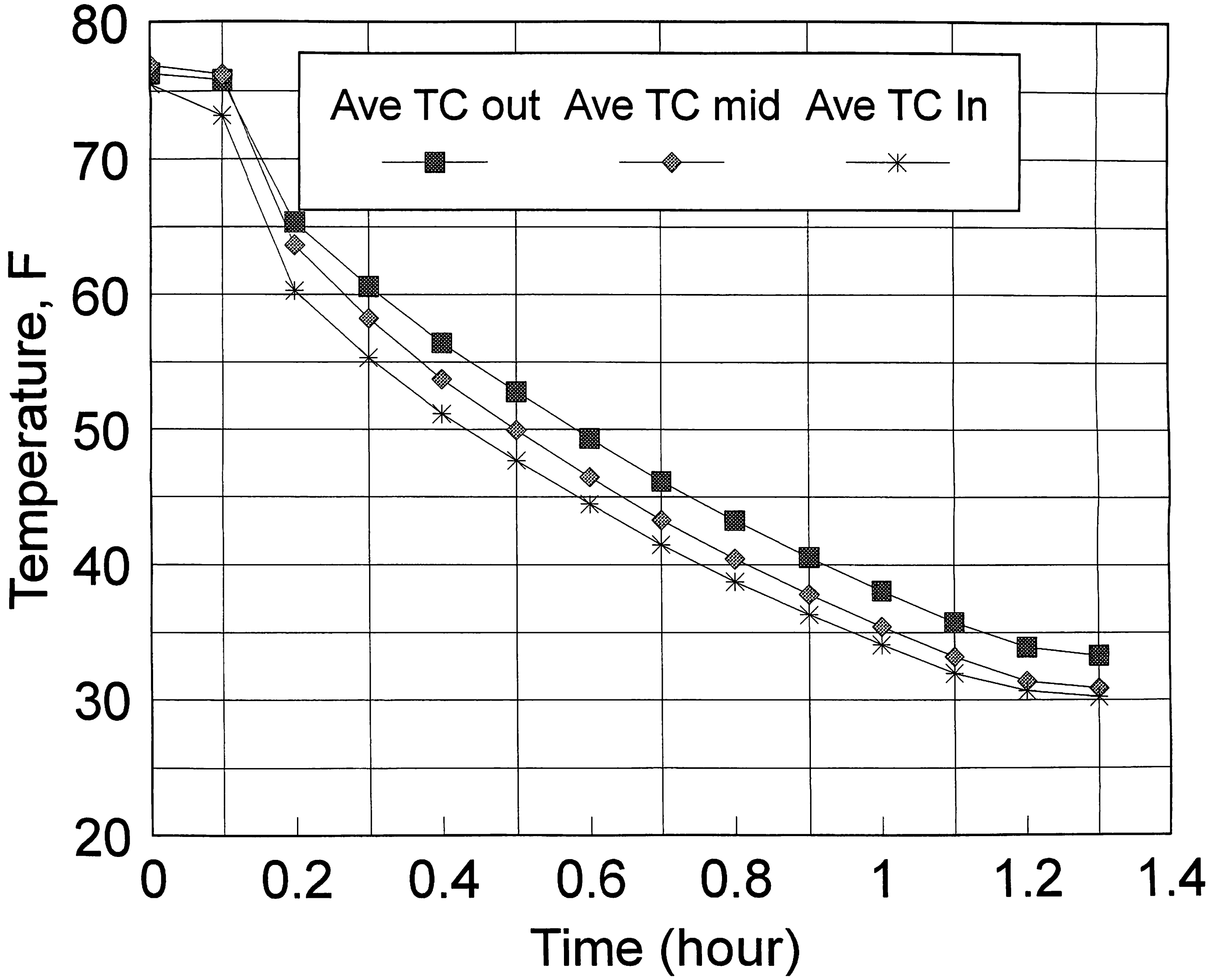

Figure 7. Temperature gradient in air flow direction for 16 × 20 flat and pint clamshell (Test 2).

prove beneficial during subsequent cold storage, they do not appear to have much influence on the precooling time.

A comparison of 12 × 20 flats (Test 7) packed the same except that the two semi-circular vents at the bottom edge shown in Fig. 4 were either left open or sealed with duct tape resulted in a slight difference in cooling rates. Blocking the two vent holes reduced the vent open area from 15.7% to 14.9%. As expected, the minor reduction in vent open area produced a small increase in the cooling time.

Figures 5 and 6 illustrate the cooling curves (average of 30 thermocouples) for the cooling data presented in Table 1. Figure 5 (Test 2) graphically demonstrates that the pint clamshell cooled at a slightly faster rate than the quart clamshell. Figure 6 (Test 7) shows that the 12 × 20 flat with the bottom vents open (untaped) and with the bottom vents taped, cooled at approximately the same rate, although the initial temperatures were different.

Figures 7 and 8 show the temperature gradient in the direction of air flow. The average temperature for strawberries near the cooling air entrance, near the middle of the pallet, and near the cooling air exit, are represented by Air In, Air Mid, and Air Out, respectively. The closer the three curves are grouped, the more uniform the cooling. The pint clamshell provided more uniformity of cooling in the direction of air flow than the quart clamshell.

The percent moisture loss that occurred during the forced-air cooling tests is shown in Table 1. The average water loss ranged from 0.5% to 1.25% among the treatments. The strawberries in pint mesh baskets in the standard flat lost more than twice as much water during cooling as strawberries in pint clamshells in the same flat. Among the berries in clamshells, those in quart clamshells tended to lose more water than those in pint clamshells, although there was no significant difference (P=0.05) in water loss between pint and quart clamshells in the non-vented 16 × 20 flat. Differences in average moisture loss among the clamshell treatments appeared to be more closely associated with uniformity of cooling than with average cooling time.

Three-dimensional plots (not presented) of the moisture loss for all the containers on the instrumented layer of flats re-

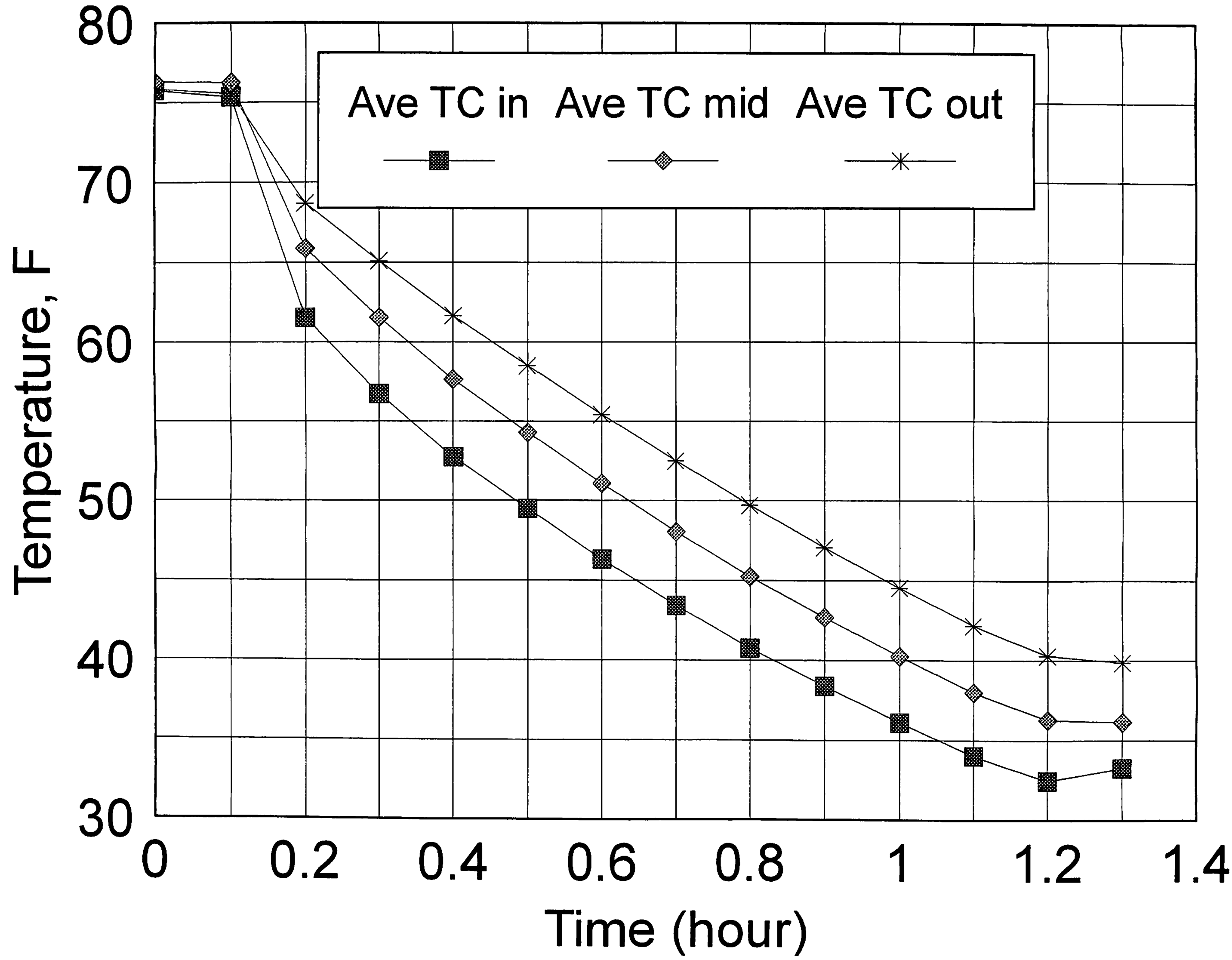

Figure 8. Temperature gradient in air flow direction for 16 × 20 flat and quart clamshell (Test 2).

vealed, as expected, that the strawberries in flats on the outside, closer to the air entrance, lost less moisture than strawberries on the inside, near the air exit from the pallet into the tunnel. The entering air is colder and has less water holding capacity. As the cooling air passes through the pallet, the air temperature increases and the water holding capacity increases.

Moisture loss can cause reduction in the grade of strawberries. Additional research is needed to evaluate the impact and magnitude of moisture loss during forced-air cooling as well as during the cold storage period. During forced-air cooling, the berries are exposed to high vapor pressure deficits, but for a short time. During the cold storage phase, the berries are exposed to a lower vapor pressure deficits, but for an extended length of time.

Limited humidity measurements were taken to determine changes in the moisture content of the cooling air. Problems with the aspirated wet bulb equipment developed for all but one test. The relative humidity of the cooling air entering and leaving the pallet of strawberries during forced-air cooling Test 6 is shown in Fig. 9. The relative humidity of the incoming air (RH in) was between 80 and 85%, while it was approximately 75% for the air inside the cooling tunnel (RH out). The incoming relative humidity was expected to be in the range 90 to 95%, perhaps indicating a need for additional humidification.

A better method for measuring continuous air moisture during forced-air cooling should be devised and tested. Plans to measure air moisture changes during forced-air cooling in a cooler with and without a humidifier were also halted due to mechanical problems at the cooler and the end of season. There is a need to conduct additional studies to develop a good measuring tool and to determine if adding humidification is an advantage.

Pallets are placed end to end to form each side of a cooling tunnel in forced-air cooling. It is important that the pallets are placed such that very little gap exists between the cartons of adjacent pallets. Otherwise another path is created for the cooling air to bypass the cartons. After one test was set up, a 6-inch gap the full height of the pallets was discovered and then closed by use of a forklift to move the pallets together. Talbot *et al.* (1991) reported significant air flow through such gaps, particularly when plastic was installed to seal the side openings of the pallets. The more difficulty for the air to

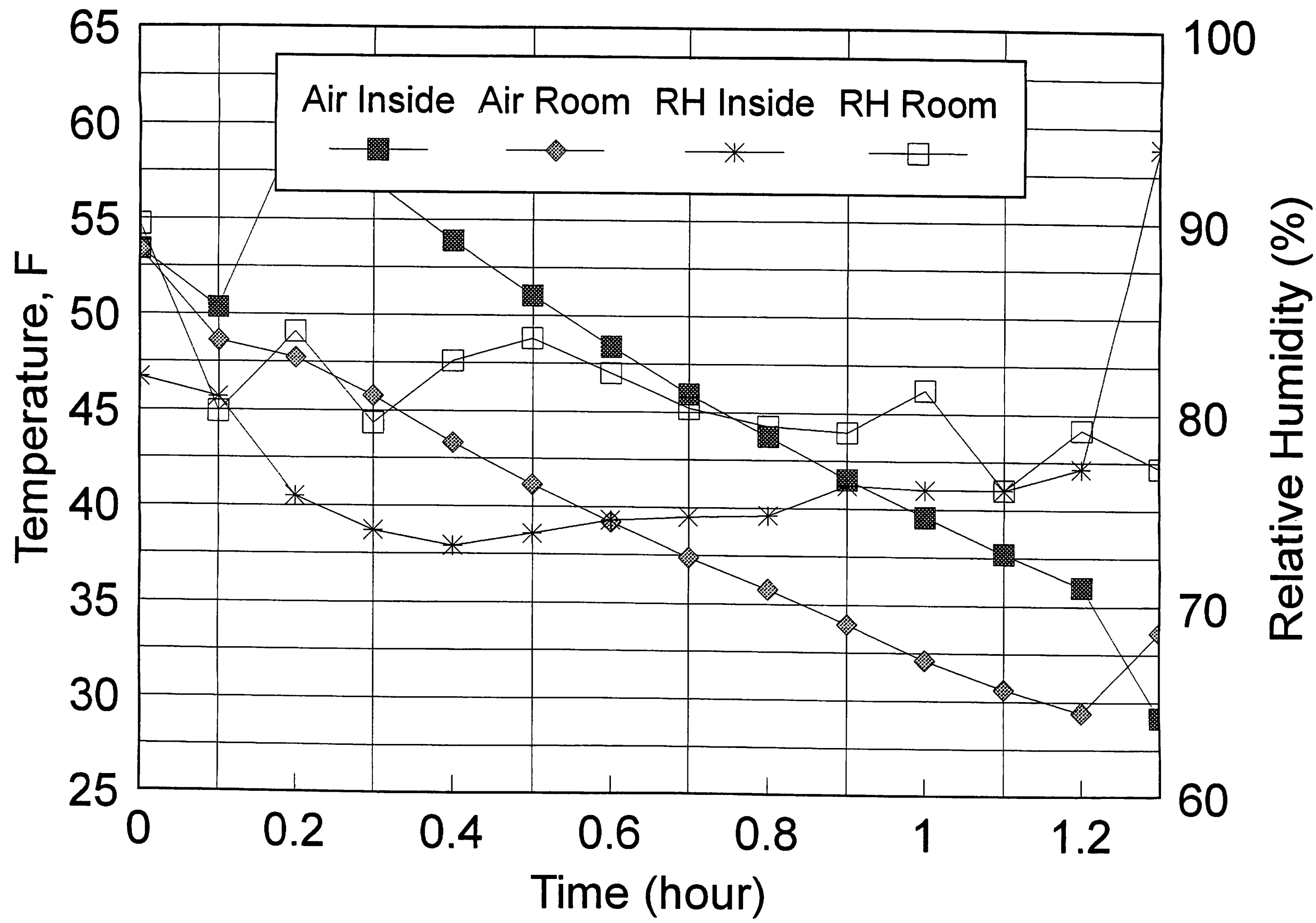

Figure 9. Relative humidity (air moisture) during forced-air cooling for 12 x 20 flat and mesh pint (Test 6).

flow through the packages, the more important eliminating air bypass becomes.

Static pressure differences with and without the plastic covering the pallet side openings were measured. Sealing the pallets increased the pressure drop by 33%. This could provide up to 15% more cooling air through the berries.

These tests were conducted with a cooling system with air flow, static pressure drop, and refrigeration capacity far exceeding minimum requirements. On systems operating at or past peak capacity, the differences between packaging configurations probably would produce more variation in cooling times.

Conclusions

Pint clamshells do not cool significantly slower than mesh baskets. Pint clamshells cool slightly faster than quart clamshells but this may be related to the clamshell venting rather than the size. The 16 × 20 flats without additional vents cooled more rapidly than the flats with additional bottom vents, which challenges claims of a venturi cooling affect. The 16 × 20 flats without dividers and with vertical slot vents performed well and should be evaluated further as a potential improved packaging system. Moisture loss was greatest in mesh baskets and tended to be greater in quart clamshells than pint clamshells. Additional studies should further evaluate moisture loss during forced-air cooling. Humidifiers may help reduce moisture loss during cooling and additional research should be performed. Plastic clamshell manufacturers and corrugated container manufacturers should collaborate with grower/shippers and researchers to design optimum cooling systems with proper vent alignment between the strawberry containers and flats. Cooling management is extremely important. When 40 × 48 pallets are used in forced-air cooling it is extremely important to seal the open sides of the pallets. Failure to take this important management step will cause increased cooling times.

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Literature Cited

Arifin, B. B. and K. V. Chau. 1988. Cooling of strawberries in cartons with new vent hole designs. Trans. Amer. Soc. Heating, Refrig. Air Conditioning Eng. 90:1415-1426.

Baird, C. D., J. J. Gaffney, and M. T. Talbot. 1988. Design criteria for efficient and cost effective forced air cooling systems for fruits and vegetables. Trans. Amer. Soc. Heating, Refrig. Air Conditioning Eng. 94:1434-1454.

Cady, S. 1995. Strawberry Package Comparison. Hillsborough County Coop. Ext. Serv. Research Rept. 8 p.
Emond, J. P., F. Mercier, S. O. Sadfa, M. Bourre, and A. Gakwaya. 1996. Study of parameters affecting cooling rate of strawberry and airflow patterns in forced-air precooling process. ASAE paper FPE-1269. Amer. Soc. Agr. Eng., St. Joseph, MI. 34 p.
Florida Department of Agriculture and Consumer Services. 1996. Florida Agricultural Statistics. Vegetable Summary 1994-1995. Fla. Agric. Statistics Serv., Fla. Dept. Agric. & Consumer Serv., Orlando.
Kader, A. A., R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. 1985. Postharvest technology of horticultural crops. California Coop. Ext. Serv. Pub. 3311.
Mitchell, F. G., R. Guillou, and R. A. Parsons. 1972. Commercial cooling of fruits and vegetables. California Agr. Expt. Sta. Man. 43.
Parsons, R. A., F. G. Mitchell, and G. Mayer. 1970. Forced-air cooling of palletized fresh fruit. ASAE Paper No. 70-875. Amer. Soc. Agr. Eng., St. Joseph, MI. 12 p.
Sargent, S. A., M. T. Talbot, and J. K. Brecht. 1988. Evaluating precooling methods for vegetable packinghouse operations. Proc. Fla. State Hort. Soc. 101:175-182.
Singh, S. P. 1991. New package system for fresh strawberries and raspberries. ASAE paper 91-6017. Amer. Soc. Agr. Eng., St. Joseph, MI. 15 p.
Talbot, M. T. and C. D. Baird. 1991. Evaluating commercial forced-air precoolers. ASAE Paper 91-6021. Amer. Soc. Agr. Eng., St. Joseph, MI. 20 p.
Talbot, M. T., S. A. Sargent, C. D. Baird, and J. K. Brecht. 1993. Design and evaluation of a standardized pepper container. ASAE Paper 93-6009. Amer. Soc. Agr. Eng., St. Joseph, MI. 23 p.

Proc. Fla. State Hort. Soc. 108:268-272. 1995.

TOMATO COLOR DEVELOPMENT FOLLOWING EXPOSURE TO ETHYLENE AT HIGH TEMPERATURES

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Abstract. **Tomato (*Lycopersicon esculentum* L. Mill.) fruit ripening is reversibly inhibited at high temperatures (30C and above). In this study, the ability of tomatoes to respond to ethylene treatment at high temperatures in terms of red color development was investigated. Mature green (MG) Agriset 761 tomato fruit were exposed to 100 ppm ethylene at 20, 25, 30, 35, or 40C and 95% relative humidity (RH) for 24, 48, or 72 hr, then transferred to air at 20C for ripening. Tomatoes exposed to ethylene at high temperatures for 24 hr showed little difference in color development compared to those exposed to ethylene at lower temperatures. Increasing the duration of ethylene/high temperature treatment to 48 and 72 hr at 35 or 40C inhibited subsequent red color development at 20C while prior exposure to 30C stimulated color development. These results suggest that tomatoes can perceive ethylene at high temperatures, but are slow to respond in terms of color development until transferred to a lower temperature.**

Tomatoes are produced in Florida over about a nine-month season from late September through June, with the areas of production moving from northern Florida in the early fall to southern Florida in the winter, and the reverse occurring in the spring. Tomato is the highest valued vegetable grown in Florida, accounting for about 30 percent of the total production value among major Florida vegetables during the 1993-1994 season (Freie and Pugh, 1995). The average value of the Florida fresh market tomato crop for the years 1989-1994 was $574.3 million (Freie and Pugh, 1995).

About 85% of the tomatoes produced in Florida are harvested when green and ripened after harvest (Fla. Tomato Comm., 1995). The harvest operation usually begins in mid-morning, and harvested tomatoes are accumulated in field bins or gondolas before transport to the packinghouse. Harvested tomatoes are usually held under shade cover until they are run over the packingline. The packinghouse operations are typically begun in the afternoon and continue until that day's harvest has been processed. The first step in the packinghouse operation is the dumping of tomatoes from the field bins or gondolas into a heated, chlorinated water receiving tank. The water in the receiving tank is maintained 5C higher than the highest fruit pulp temperatures to avoid infiltration of decay organisms into the tomatoes (Sherman et al., 1981). The tomatoes are then washed, treated with waxes or other food grade coatings, graded, sized, packed in shipping containers, and the containers stacked on pallets.

Mature green tomatoes are commonly treated with supplementary ethylene at about 20 to 21C and 85 to 95 percent RH in ripening rooms to provide for faster and more uniform ripening (Hardenburg et al., 1986). Tomatoes are typically held in the ripening rooms for 1 to 3 days, with daily inspections to determine when almost all the fruit have begun to develop red color. Although the ripening rooms used to treat MG tomatoes with ethylene are maintained at 20 to 21C, the pulp temperature of fruit placed in these rooms may be well over 30C (Brecht and Sargent, unpublished). Tomato ripening rooms are generally not designed for efficient cooling of the tomatoes (Sherman and Talbot, 1986). Thus, it is likely that tomatoes may remain above 30C for a substantial time while being treated with ethylene in ripening rooms. After removal from ripening rooms, tomatoes are usually shipped to market in refrigerated trucks at about 12 to 15C.

Tomato color development during ripening and postharvest storage is influenced by many factors. Under normal dis-

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