FORCED-AIR COOLING PACKAGED BLUEBERRIES

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ABSTRACT. *Harvested blueberries, packaged in plastic covered 0.47-L (1-pt) fiber cups, arranged 12 cups to a corrugated master and palletized (96 masters to a pallet) were cooled with forced-air pulled horizontally through the stack. Air flow rates varied from 0.0011 to 0.0022 $m^3/s/kg$ (1.06 to 2.12 cfm/lb) of fruit. The variations in cooling rates are discussed in terms of time required to reduce the temperature one-half the difference between the starting pulp temperature and the room air temperature. Average cooling half-times ranged from 48 to 65 min for forced-air cooled fruit. The variations were attributed to differences in the air flow rate. With forced-air cooling, the differences in cooling rates at various points inside the pallet were generally small. For comparison, similar pallets were room cooled at the same time and location. The average half cooling time near the center of the pallet of room-cooled fruit was projected to be over 12 h. Average half cooling times for fruit near the outside of the pallet was approximately 6 h, indicating significant internal temperature variations. The results of this study suggest that the application of forced-air cooling can significantly reduce cooling times of packaged and palletized blueberries and provide more uniform temperatures within the pallet.*
Keywords. *Blueberries, Forced-air, Postharvest, Refrigeration, Packaging.*

Blueberries of the highbush type (*Vaccinium corymbosum* L.) and the rabbiteye type (*Vaccinium ashei* Read) are grown in North Carolina. More than 90% of the commercial blueberry production is of the highbush type. Harvest of highbush blueberries begins in late May and often continues through late June. Rabbiteye varieties ripen in late June and harvest continues into August. Most commercial blueberries in North Carolina are produced by grower members of marketing co-ops. These co-ops operate one or more cooling and shipping facilities and assume the quality control and marketing responsibilities for their grower members.

Most consumers purchase fresh blueberries on impulse and are prompted primarily by the perception of quality. Wholesale buyers also associate appearance, lack of moisture, and firmness with fruit quality and freshness. Successful blueberry marketing requires the fruit be of highest quality and appearance. Blueberries are extremely perishable and easily damaged by rough handling, moisture, and adverse temperatures. Because blueberries are often harvested and handled during hot, humid weather, careful attention to proper postharvest handling is essential to quality maintenance (Boyette et al., 1993).

Blueberries continue to respire and produce heat after harvest. Cooling reduces the respiration rate and increases the length of time before the inevitable decline in quality has rendered fresh berries unsuitable for the market. The respiration rate of blueberries at 27°C (80°F) is more than 10 times the rate at 4°C (40°F) (Hardenburg et al., 1986). Besides the physiological damage (primarily softening) that results from over-ripening, warm blueberries provide an ideal site for various postharvest diseases (Cappellini and Ceponis 1984).

Blueberries should be cooled as quickly as possible after harvest. The optimum temperature is 1°C (34°F) although in practice, pulp temperatures in the range of 3 to 4°C (38 to 40°F) have been shown to be sufficient for acceptable shelf life (Hardenburg et al., 1986). Proper control of refrigeration temperature is important because blueberries will freeze at approximately –2°C (28°F). Freezing renders blueberries unsuitable for the fresh market. Although a low relative humidity may be beneficial initially during cooling to remove surface moisture, for optimum storage the fruit should be held at 90% relative humidity. Under optimum conditions, blueberries may be held in marketable condition for a week or more.

Until recently, most North Carolina blueberries destined for wholesale channels were cooled by placing the packaged and palletized fruit into a refrigerated room (room cooling) for an indefinite but generally short period while awaiting shipment. This arrangement has proven unsatisfactory since a portion of the fruit often reaches the consumer in poor condition as a result of insufficient cooling (Cowan, 1989). Consequently, the effectiveness of cooling, not its availability, is the deciding factor in quality. For cooling to be effective, it must be thorough and consistently applied.

The lack of time for proper cooling arises because it is often at cross-purposes with assembling truckload lots and making timely deliveries. For a variety of reasons, growers generally deliver the palletized fruit to the co-op's cooler in

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the late afternoon or early evening. Shippers, fully understanding that they have a warm, palletized and highly perishable commodity on their hands, are anxious to assemble a truckload lot and get it on its way to the buyers. More often than not this means that pallets of berries remain in the cooler no more than an hour or so. Although shipment to market may take as long as 12 h and is always via refrigerated trucks, experience has shown that this period of refrigeration contributes little reduction in fruit temperature (Sansone, 1989).

Forced-air cooling, the pulling of refrigerated air through bulk or packed produce, has been shown to greatly decrease cooling time when compared with room cooling (Parsons et al., 1972). Forced-air cooling may be applied either with stationary or portable fans. Proper fan selection is critical since cooling rate is very dependent on the air velocity past the produce (Arifin and Chau, 1987). Other factors affecting the cooling rate are the size and shape of the produce, the packaging construction and arrangement of the packages. (Mitchell et al., 1972; Baird et al., 1988; Talbot et al., 1992). Although the rudiments of forced-air cooling are understood by North Carolina blueberry shippers, prior to this study it was thought that the packaging, particularly the plastic covering on the cups, would make forced-air generally ineffective.

The objectives of this study were to:

- Determine and compare the cooling rates and temperature gradients within pallets of fruit packaged to industry standards and subjected to forced-air cooling versus room cooling.
- Determine the relationship between air flow rate and cooling rate for pallets of forced-air cooled fruit.

Methods and Equipment

At the invitation of two southeastern North Carolina blueberry cooperatives, tests were conducted to compare room cooling and forced-air cooling of packaged, palletized fruit. Six tests were conducted at three cooling and shipping facilities during the 1990 harvest season. Tests number 1 and 2 were conducted at Carolina Blueberry Cooperative Association, Inc., Burgaw, North Carolina, on 30 May. Tests number 3 and 4 were conducted at American Blueberries, Inc. Burgaw, North Carolina, on 5 June. Test number 5 and 6 were conducted at American Blueberries, Inc. at White Lake, North Carolina, on 11 June. This information is summarized in table 1.

A single corrugated berry master has dimensions of 33.5 cm (13.3 in.) wide, 50.8 cm (20 in.) long, and 10.2 cm (4 in.) deep. Each holds twelve 0.47-L (1- pt) cups in a 3×4 grid. These cups may be either fiber (pulp) or molded plastic. Fiber cups are generally favored by North Carolina blueberries producers. Fiber cups typically have approximately 5% open space on their sides. Cups are closed with a solid film label held in place with a rubber band. The film does not cover the openings on the sides of the cups. Six masters are arranged to form a layer approximately 1.02 m (40 in.) on a side. A stack of 16 layers forms a pallet of 96 masters with a gross weight of approximately 550 kg (1,210 lb). A well-stacked pallet is rather compact, but maintains approximately 1.27 cm (1/2 in.) head space above each cup to prevent crushing and to promote ventilation. Small fruit-like blueberries are easily damaged and require well-designed and substantial packaging. However, the plastic film labels, the fiber cups, the paper board masters, and especially the air gaps between the cups act as a significant and effective insulation slowing the movement of heat.

Temperatures of the fruit and air were measured with a pair of Omega Engineering model DSS-115 digital thermometers. These devices have a specified accuracy of ±0.5° C and will accept input from up to 10, type T, dial selectable thermocouples. In general, temperatures were manually recorded at 5-min intervals during the first hour of cooling, at 10- to 15-min intervals during the second hour, and at 30-min intervals thereafter. Forced-air cooling tests were terminated at the end of 2 h. However, room cooling tests were allowed to continue for 10 h.

Each thermocouple was placed inside an individual fruit. The thermocouple wire size used in all tests was 0.254 mm (0.010 in., AWG 30). Fruit containing the thermocouples were then positioned in the center of a cup. Cups with the thermocouples were then positioned throughout the pallet of fruit as shown by the diagram in figure 1. The positioning of the six thermocouples remained the same for each test. The intent of this arrangement was to measure temperatures at representative positions in the pallet of fruit to determine the magnitude of temperature gradients that might develop during cooling.

For each forced-air test, four, six, or eight pallets of field warm fruit, each of ninety-six 12-pt flats, were positioned in two solid parallel rows. Pallets were carefully aligned to reduce air gaps between adjacent pallets. There was a 45.7 cm (18 in.) wide space between the two rows. This

Table 1. Blueberry cooling test summary

Test No.	Cooling Method	Initial Fruit Temp. °C (°F)	Room Air Temp. °C (°F)	Air Flow Rate (m³/kg-s)	Half Cooling Time (min)
1	Forced-air	20.5 (69)	4.4 (40)	0.0015	57
2	Room cooling	21.1 (70)	4.4 (40)	*	> 600
3	Forced-air	23.9 (75)	7.2 (45)	0.0011	65
4	Room cooling	25.0 (77)	7.2 (45)	*	> 600
5	Forced-air	25.6 (78)	5.6 (42)	0.0022	49
6	Room cooling	26.7(80)	5.6 (42)	*	> 600

* Not measured, convective cooling only.

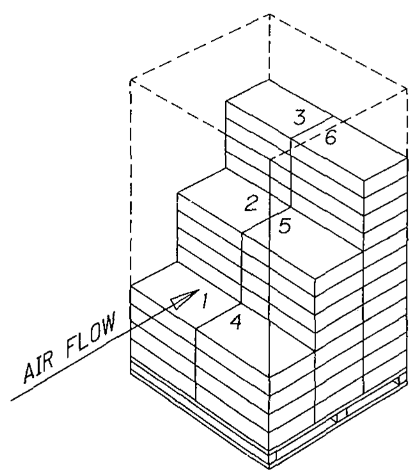

Figure 1–Location of thermocouples in pallet of fruit.

width is sufficiently wide to allow for good access and air flow yet does not waste floor space.

The forced-air cooling fan used in all three tests was a Grainger part number 3C675. This is a 91.4 cm (36 in.) diameter vertical blade, direct drive fan mounted inside a wood enclosure approximately 1.4 m (41 in.) on a side by 0.43 m (16 in.) deep. Attached to the fan was a length of plastic-coated fabric measuring 0.91 m (36 in.) wide by 7.32 m (24 ft) long. The fabric ran from the fan over the top of the space between the rows of pallets and all the way to the floor at the end opposite the fan. This formed an enclosed plenum into which air could be drawn horizontally through the pallets of fruit and out through the fan. Single entry pallets with the solid sides perpendicular to the air flow was used in all tests (fig. 1.)

The rated capacity of the fan is approximately 4.63 m^3/s at 0.0249 kPa (9810 cfm at 0.10 in. of water) static pressure. During each forced-air cooling test, the static air pressure was maintained at 0.0249 kPa (0.10 in. of water) by adjusting the width of a small air gap between the end of the plastic cover and the floor. Static air pressure was measured with a Dyer Mark II, inclined tube manometer.

Pallets of field-warm fruit used in the room cooling tests were simply placed into a refrigerated room out of the direct airflow from the refrigeration coils.

Results and Discussion

Normalization of temperature data provides a convenient method for comparing tests with different starting, ending, and room air temperatures. Time and temperature data from each test were normalized for purposes of analysis using equation 1.

$$R_n = (T_x - T_r)/(T_i - T_r) \quad (1)$$

where

R_n = normalized temperature ratio at a specified time
T_x = fruit temperature at a specified time, t (°C)
T_r = average room temperature (°C), assumed to be constant
T_i = initial fruit temperature (°C)

Figures 2a, 2b, and 2c are graphs of the normalized temperatures from the three forced-air cooling tests (tests 1, 3, and 5, respectively, as indicated in table 1). With the exception of beginning pulp and air temperatures, and air flow rates, all other parameters of these three tests were the same. Variations in beginning pulp temperatures within each pallet were generally less than 2°C (4°F) and were minimized by allowing the pallet to sit undisturbed in ambient air for approximately one half hour before the commencement of cooling. Test 5 (fig. 2c) shows the smallest variations in internal cooling rate that is consistent with the fact that test 5 had the greatest air flow rate and hence a more uniform heat transfer rate.

Figure 3 is a summary graph of the three forced-air cooling tests. Each curve is an average of normalized values from the six thermocouples positioned throughout the pallet. Although the results of these tests are similar (particularly when compared to the room cooling tests), the variations may be attributed to differences in air flow rate. There appears to be a nearly linear relationship ($r^2 = 0.98$, fig. 4) between air flow rate and cooling time over the range tested. Although the relationship is assumed to be exponential over a much larger range, this work suggests a method to reasonably predict cooling times over a limited practical range based on a linear function of air flow rate.

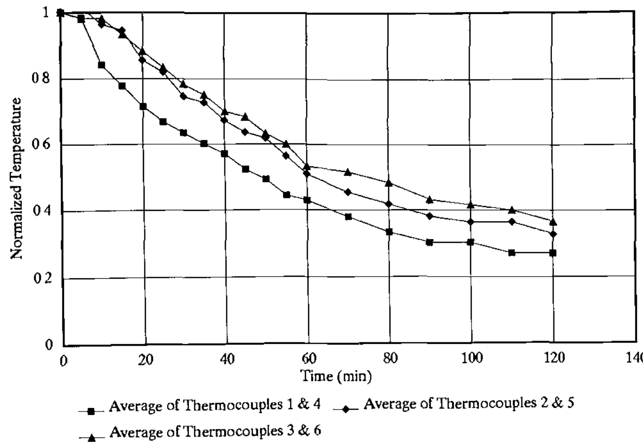

Figure 2-(a) Test 1 – Forced-air, normalized temperatures (thermocouples 1 through 6).

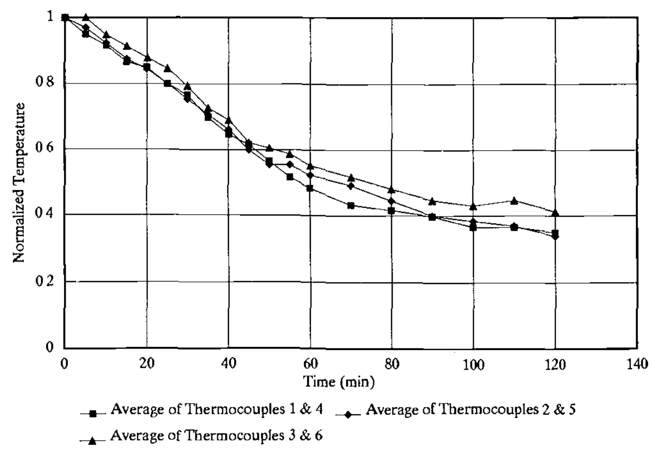

Figure 2-(b) Test 3 – Forced-air, normalized temperatures (thermocouples 1 through 6).

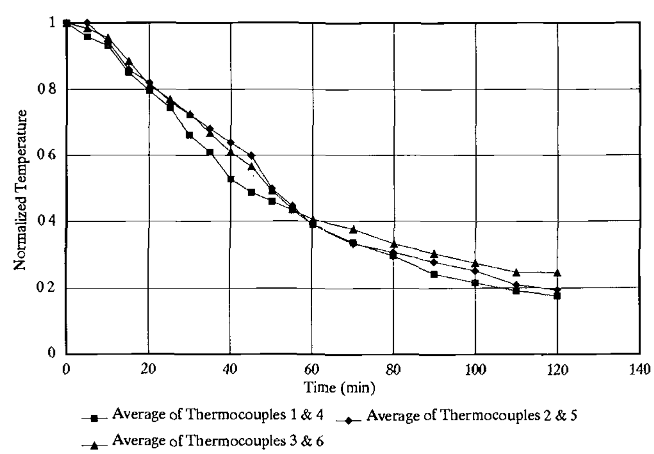

Figure 2-(c) Test 5 – Forced-air, normalized temperatures (thermocouples 1 through 6).

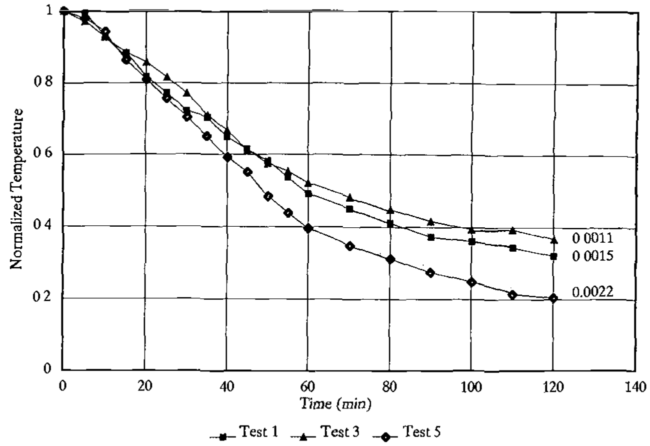

Figure 3–Normalized average temperatures from tests 1, 3, and 5 (thermocouples 1 through 6).

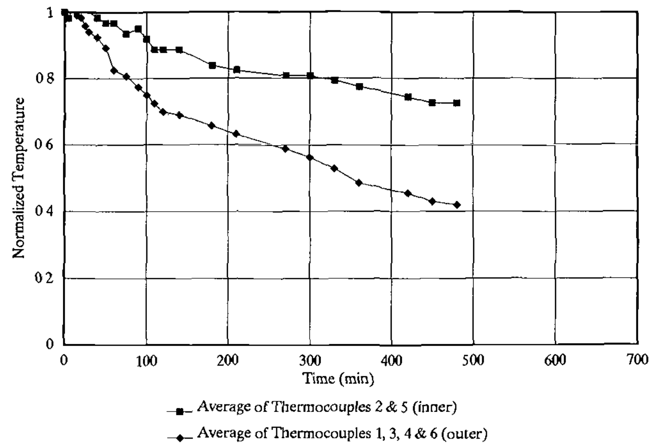

Figure 5–(a) Test 2 – Room cooling, normalized and averaged temperatures.

Figures 5a, 5b, and 5c are graphs of the normalized temperatures from the three room cooling tests (tests 2, 4, and 6, respectively). The upper curve of each graph is an average of the normalized temperatures from the two inner most thermocouples (locations 2 and 5 as shown in fig. 1) and the lower curve represents values from two of the outer most thermocouples (locations 1, 3, 4, and 6). All parameters except beginning and room air temperatures were the same as with the forced-air cooling tests. Unlike the data from the forced-air cooling tests, these data show considerable variations in cooling rates by position within the pallet of fruit. As expected, those locations nearer center of the pallet cooled much slower than those near the outside. After 8 to 10 h of room cooling, none of the inner-most fruit had achieved half cooling. Those near the outside achieved half cooling in approximately 6 h. At the end of the room cooling test, it was not uncommon to observe internal temperature variations of as much as 10°C (18°F).

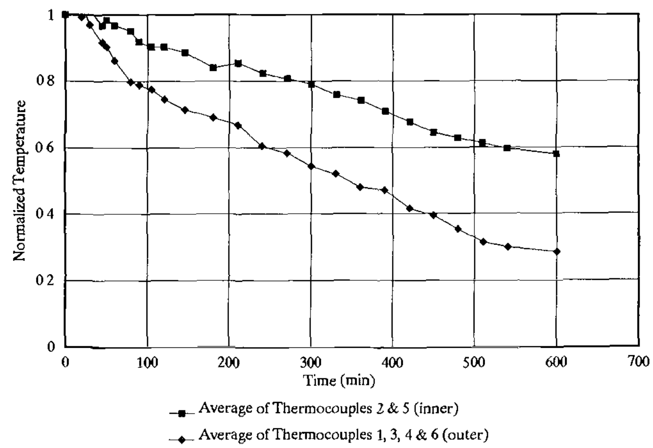

Figure 5–(b) Test 4 – Room cooling, normalized and averaged temperatures.

Figure 6 is a graph showing the normalized averages of the data from the three forced-air cooling tests (test 1, 3, and 5) plus the normalized and weighted averages of the inner and outer most locations of the room cooling tests

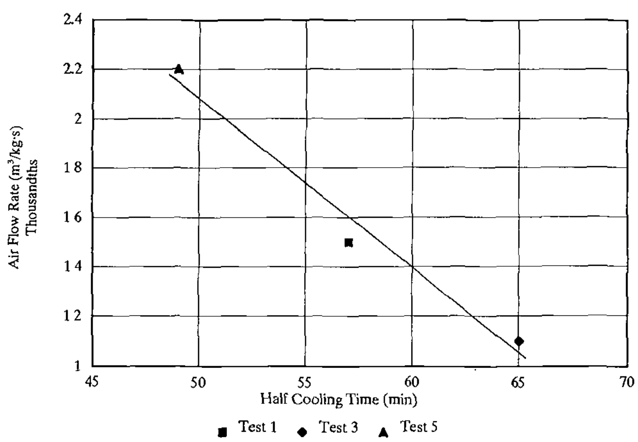

Figure 4–Comparison of air flow rate and half cooling times, tests 1, 3, and 5 (R^2 = 0.98).

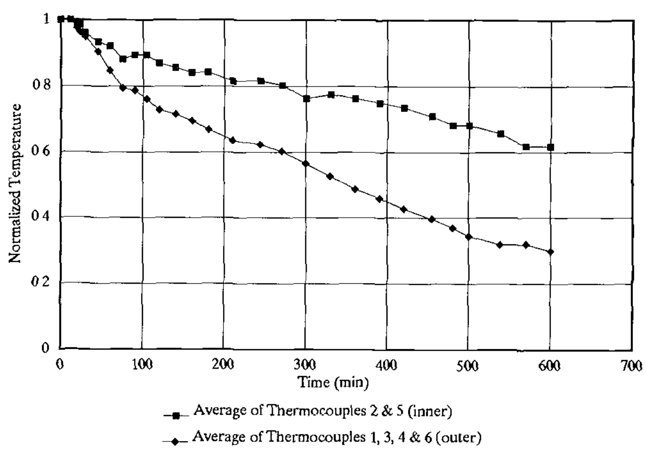

Figure 5–(c) Test 6 – Room cooling, normalized and averaged temperatures.

(test 2, 4, and 6). It is clear from this graph that forced air cooling greatly accelerates heat transfer when compared to room cooling. Reduction in half cooling time appears greater than 10 to 1.

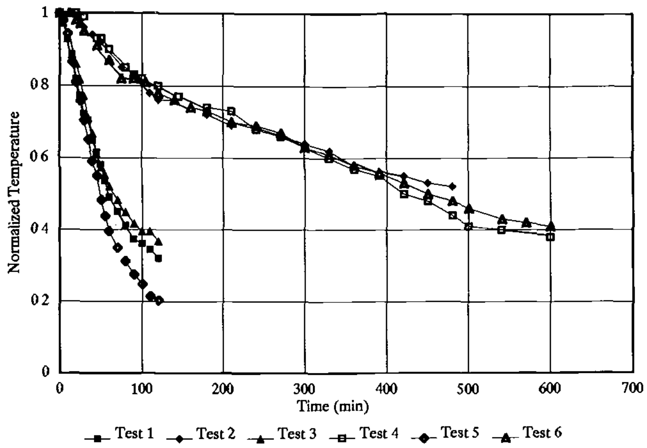

Figure 6–Normalized weighted average temperature summary from tests 1 through 6.

Summary and Recommendations

Six field tests were conducted during the 1990 season to compare the cooling rates of forced-air versus room cooling. These tests indicate that forced-air cooling is over 10 times more rapid than room cooling over the forced-air flow ranges investigated. Additionally, forced-air cooling results in more space-wise uniform temperatures through the entire pallet load. There was less internal variation in temperature with forced air cooling as compared to room cooling.

Providing sufficient refrigeration capacity already exists, an additional nominal investment in forced-air cooling fans can dramatically reduce the time required to satisfactorily cool blueberries. However, where sufficient capacity does not exist, the addition of forced-air cooling fans can quickly make the lack of capacity obvious. Properly applied, forced-air cooling can result in the delivery of a consistently higher quality product to the consumer. Although this research was conducted on packaged blueberries, it may be applicable to other similarly packaged small fruit such as strawberries, brambles and cherry tomatoes. Observation concerning the relationship of air flow rate and cooling times suggest a need for more research to determine the optimum balance of fan and energy cost versus reduction in cooling time.

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