CIR942

UNIVERSITY OF FLORIDA
IFAS EXTENSION

Precooling Strawberries [1]

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Strawberries are one of the most delicate and highly perishable fruits. Their nonclimacteric physiological characteristics dictate that they must be harvested in an essentially ripe condition. The quality of fresh strawberries depends on their maturity and appearance (red color intensity and distribution, fruit size and shape, freedom from defects and decay), firmness, and flavor (determined by amounts of sugars, organic acids, phenolics, and characteristic aroma volatiles). The principal decays likely to affect strawberries are gray-mold and Rhizopus rots. Even a small amount of infestation can quickly spread throughout an entire package.

The most important factors in attaining and maintaining good quality are harvesting at the fully-ripe stage, avoiding physical injuries during all handling steps, enforcing strict quality control procedures, prompt precooling, and providing proper temperature and relative humidity during transport and handling at destination.

Loss of strawberry quality is not acceptable to consumers. The parameters which largely determine quality cause the quality to decrease rapidly at ambient temperatures; therefore, proper temperature management is important. Proper temperature management of strawberries begins with precooling (rapid removal of field heat) from field temperatures which can be as high as 30°C (86°F). Rapid removal of field heat is critical to retard deterioration of strawberries. The recommendation for maximum quality retention of strawberries is precooling to near 0°C (32°F) within 1 hour of harvest and maintaining at 0°C (32°F) throughout the marketing channels [3]. For commercial strawberry operations in Florida, cooling to this ideal criterion is approached (in practice strawberries are cooled and shipped at 21 to 5°C (35, to 41°F)) but depends on various factors, including volume of strawberries handled, cooling and handling equipment availability and capability, economics, energy, and market conditions.

Strawberries are an important crop in the United States. Nationally, Florida follows California in fresh strawberry production with an average annual value of $68.4 million for the last 5 years [2]. Fresh strawberry yields in Florida averaged 1,867 flats per acre with 9.5 million flats packed off 5.1 thousand acres, with a season average f.o.b. of $7.20 per flat over the last 5 years, with record crops the last two years.

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Strawberry growers and packers in Florida are aware of the value of their crop and of the quality demands of consumers. They are using good temperature management but are interested in additional improvements. Most strawberries in Florida are forced-air cooled in fiberboard flats stacked on pallets. Room cooling of strawberries is not an acceptable precooling method nor is reliance on refrigerated trucks during transit.

This publication presents quality parameters, cooling requirements, cooling methods, and management guidelines for maintaining the quality of Florida strawberries. Studies conducted to establish the relationship between cooling rate and air flow rate and the effects of new vent hole designs on cooling rates of strawberries are discussed. Management guidelines or recommendations to the packinghouse operators concerning possible system performance improvements are presented, such as increasing resident time within the forced-air precooler to achieve better cooling or lowering the cold room temperature to prevent warming of precooled strawberries.

Quality parameters

United States grade standards for strawberries allow for three grades: U.S. 1, Combination, and U.S. 2. The principal grade is U.S. 1. Although Florida shippers may not use U.S. grades for shipping, these, or similar grades, are used for inspection purposes at destination. Therefore, all growers should be aware of the grade specifications. If the strawberries do not meet the grade standards when they are picked, then it is simply impossible for them to make grade at destination.

Strawberries of one variety or with similar varietal characteristics with the cap (calyx) attached, which are firm, not overripe or undeveloped, and which are free from mold or decay and free from damage caused by dirt, moisture, foreign matter, disease, insects, mechanical or other means are U.S. 1. Each strawberry must have at least 3/4 of its surface showing a pink or red color and the minimum diameter of each strawberry must not be less than 3/4 inch.

Cooling requirements

Understanding of the cooling requirements of horticultural commodities requires an adequate knowledge of their biological responses. Fresh horticultural crops are living organisms, carrying on many biological processes essential to the maintenance of life. They must remain alive and healthy until processed or consumed. Energy that is needed for these life processes comes from the food reserves that accumulated while the commodities were still attached to the plant [4].

Respiration is the process by which the food reserves are converted to energy. Through a complex sequence of steps, stored food reserves (sugars and starches) are converted to organic acids and subsequently to simple carbon compounds. Oxygen from the surrounding air is used in the process while carbon dioxide is released. Some of the energy is used to maintain the life processes while excess energy is released in the form of heat, called "vital heat." This heat must be considered in the temperature management program.

The respiration rate varies with commodity, in addition to variety, maturity or stage of ripeness, injuries, temperature, and other stress related factors. Strawberries have a high respiration rate, 12 to 18 mg CO_2/kg-h (2,700 to 3,900 Btu per ton per day) at 0°C (32°F) [3]. The major determinate of respiration activity is the product temperature. Since the final result of respiration activity is product deterioration and senescence, achieving as low a respiration rate as possible is desirable. For each 10°C (18°F) temperature increase, respiration activity increases by a factor of 2 to 4 [3]. For example, the respiration of strawberries at 10°C (50°F) is 49 to 95 mg CO_2/kg-h (10,800 to 20,900 Btu per ton per day), four to five times greater than at 0°C (32°F). Therefore, strawberries must be rapidly precooled to slow their metabolism (physiological deterioration) in order to provide maximum quality and storage life for shipping and handling operations.

Strawberries are not a chilling-sensitive crop (crops which must be stored at temperatures generally above 10°C (50°F) to prevent

physiological damage). Therefore, they can be safely cooled to a temperature of 0°C (32°F). The recommendation listed in the introduction indicated the requirement of precooling to near 0°C (32°F) within 1 hour of harvest and maintaining at 0°C (32°F) throughout the marketing channels. The required rate of cooling during precooling can be expressed in terms of the half-cooling time or the 7/8-cooling time. These values remain constant for the particular set of precooling conditions from which they are determined. The half-cooling time is the time required to remove one half of the temperature difference between the initial pulp temperature and the cooling medium temperature. For commercial precooling, it is recommended [6] that 7/8 of the difference between the pulp temperature and the cooling medium temperature be removed prior to storage and transport. Under ideal circumstances the 7/8 cooling time is equal to about three times the amount of the half-cooling time.

For example, if strawberries are harvested at 30°C (86°F) and cooled in a forced-air cooler with an air temperature of 1.1°C (34°F) the half-cooling time would be the time required to remove 14.5°C (26°F)2 or for the strawberries to cool to 15.5°C (60°F)3. For the same situation, the 7/8-cooling time would be the time required to remove 25.3 °C (45-5°F)4 or for the strawberries to cool to 4.7°C (40.5°F). By developing a precooling

schedule [6] the 7/8-cooling time could be established. Therefore after precooling for a time period equal to the 7/8-cooling time or by determining the pulp temperature was 4.7°C (40.5°F) [5], the strawberries would be removed from the precooler and moved to cold storage for additional cooling to 0°C (32°F).

Cooling schedules should be utilized to maximize efficiency. Use of a schedule allows cooling times to be adjusted based on the initial temperature of the berries. Strawberries coming from the field at 18.3°C (65°F) do not need to be cooled for as long as fruits arriving at 32.2°C (90°F). Leaving strawberries in the forced-air cooler longer than necessary can lead to undesirable water loss because of rapid air movement. On the other hand, inadequate cooling can lead to rapid deterioration due to high temperatures.

Cooling methods

The selection of a particular precooling method is determined by several factors, including: the rate of cooling required, compatibility of the method with the commodities to be cooled, subsequent storage and shipping conditions, and equipment and operating costs.

During precooling, the sensible heat (or field heat) from the product is transferred to the ambient cooling medium. The rate of heat transfer, or cooling rate, is critical for the efficient removal of field heat and is dependent upon three factors: time, temperature, and contact. In order to achieve maximum cooling, the product must remain in the precooler for sufficient time to remove the heat (7/8-cooling time). This is particularly important during busy periods when it may be tempting to "push" product through the precooler. A correctly sized precooler should have sufficient capacity so as to provide adequate resident time for precooling, while at the same time not slowing subsequent packing and/or handling operations. The cooling medium (air) must be maintained at a constant temperature throughout the cooling period. If the refrigeration system is undersized for the capacity of product requiring precooling, the temperature of the medium will increase over time. The cooling medium must also have intimate contact with the surfaces of the strawberry. Inappropriately-designed containers can markedly reduce flow of the cooling medium.

The cooling rate is not only dependent upon time, temperature, and contact with the commodity; it is also dependent on the cooling method employed. As noted above, most strawberries in Florida are forced-air cooled. Hydrocooling (showering or immersion in chilled water) is not recommended because wet berries are much more susceptible to decay. Cooling with crushed or slush ice is even worse because the berries are likely to sustain physical damage. Vacuum-cooling would produce critical moisture loss and procedures using water spray could not be used. Again, room-cooling of strawberries is not an acceptable precooling method nor is reliance on refrigerated trucks during transit.

Forced-air cooling (pressure cooling)

Forced-air cooling, which has been described in detail in various publications, can solve many difficult cooling problems because it provides for cold air movement through, rather than around, containers. The system, which creates a slight pressure gradient to cause air to flow through container vents, achieves rapid cooling as a result of the direct contact between cold air and warm product. With proper design, fast, uniform cooling can be achieved through unitized pallet loads of containers. Various cooler designs can be used, depending on specific needs. Converting existing cooling facilities to forced-air cooling is often simple and inexpensive, provided sufficient refrigeration capacity and cooling surfaces (evaporator coils) are available. Some variations in forced-air cooler design are described here.

Forced-air tunnel

This is the more traditional forced-air cooling system. Essentially, two rows of pelletized containers or bins are placed on either side of an exhaust fan, leaving an aisle between rows. The aisle and the open end are then covered to create an air plenum tunnel (Figure 1). With the exhaust fan operating, a slight negative air pressure is created within the plenum tunnel. Cold air from the room then moves through any openings in or between containers toward the low-pressure zone, cooling the product as it moves. The exhaust fan can be a portable unit that is placed to direct the warm exhaust air toward the air return of the cold room, or it can be a permanent unit which also circulates the air over the cooling surface and returns it to the cold room (Figure 2).

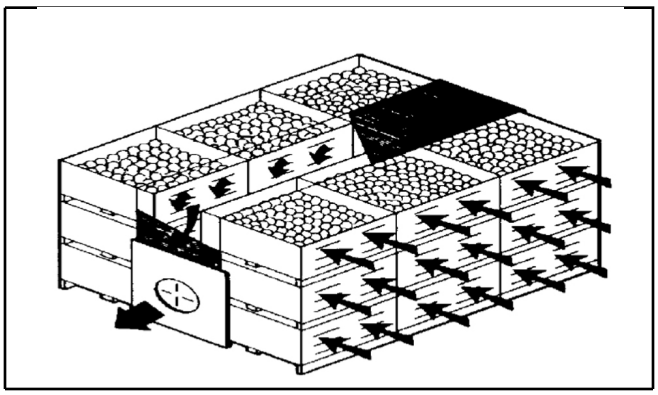

Figure 1. Forced-air tunnel with portable exhaust fan.

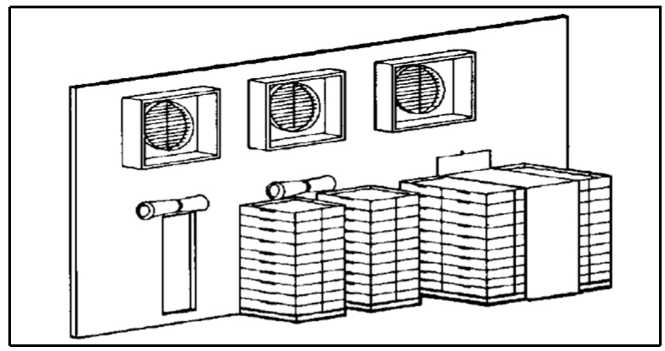

Figure 2. Forced-air cooler with permanent constructed air plenum.

Cold wall

This is a permanently constructed air plenum equipped with an exhaust fan. It is often located at one end or side of a cold room, with the exhaust fan designed to move air over the cooling surface. Openings are located along the room side of the plenum against which stacks on pallet loads of containers can be placed. Various damper designs have been developed so that air flow is blocked except when a pallet is in place. Each pallet will start cooling as soon as it is in place; thus, there is no need to await deliveries to complete a tunnel. Shelves are often built so that multilayers of pallets can be cooled with this system. Different packages, and even partial pallets, can be accommodated by proper design of the damper system. This is a benefit in some operations where a range of commodities or varieties is handled. Each pallet must be promptly moved from the cooler as soon as it is cooled in order to avoid unnecessary desiccation from continued rapid air flow over the product.

The usual design air-flow rate for strawberry cooling is 2.1×10^{-3} m^3/s per kg (2 ft^3/min per lb) of fruit with the air temperature at 1.7°C (35°F) [5]. The cooling time varies from 1.5 to 2.5 hours depending on initial temperature of the fruit. In practice, air-flow rate generally varies from 1.0×10^{-3} to 4.2×10^{-3} m^3/s per kg (1 to 4 ft^3/min per lb) of fruit.

Strawberries are usually precooled at the packinghouse in pallets consisting of 96 open-top fiberboard, single-layer tray cartons (Figure 3) containing eight 1-quart or 12 1-pint containers (Figure 4), weighing approximately 454 kg (1,000 pounds). The pallet is usually three cartons deep, two

cartons wide, and 16 high. Most boxes are constructed in such a manner that tray cartons are connected together with wires and each carton is connected to the carton below with tabs protruding up into the carton above for load stability (Figure 5). The cartons have enough open area to allow for passage of cooling air (Figure 6). Cold air is forced through the pallet and recycled through a refrigeration unit.

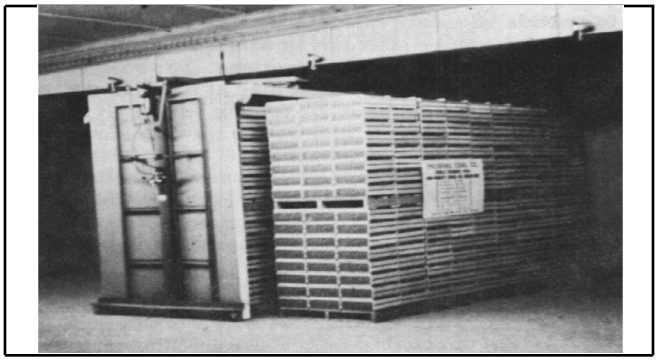

Figure 3. Forced-air cooling pallet loaded with cartons of strawberries.

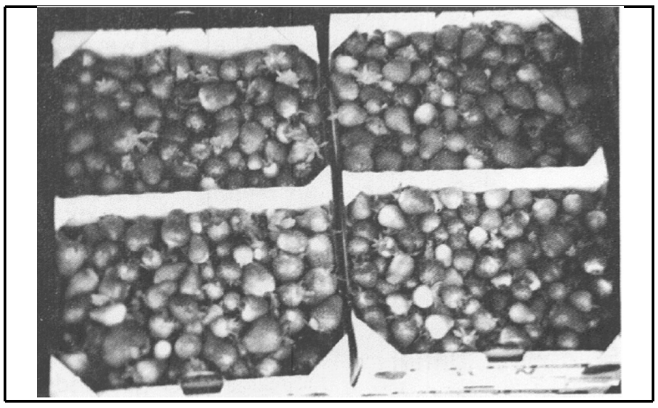

Figure 4. Wire tabs for connecting tray cartons.

Figure 5. Pint container in tray carton.

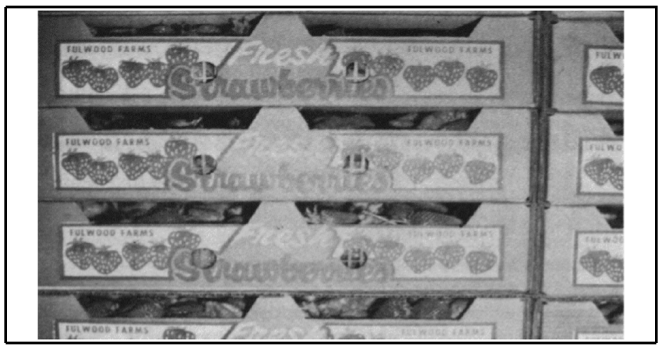

Figure 6. Vent opening in standard cartons.

Container venting

Effective container venting is essential for forced-air cooling to work efficiently. Cold air must be able to pass through all parts of a container. For this to happen, container vents must remain open after stacking. Thus, venting patterns are important. Too little venting will restrict air flow; too much venting will weaken the container.

The standard strawberry carton has a vent hole that looks like a channel with sloping sides cut in the upper fourth of two opposite sides of the carton (Figure 6). The opening represents 14% of the side of carton. Cooling experiment research [1] with other

(half-cartons were used instead of full cartons because of the symmetry of the carton design), was conducted to find the effect of different vent hole configurations. Table 1 shows the vent hole sizes and percent openings for each design. The three new vent hole designs were tested against the standard container. All new vent hole designs were found to improve cooling time. There was no significant difference among the new designs. Table 2 summarizes the effects of the new vent hole designs on the cooling time for the last basket (three cartons with three pint baskets per carton) downstream and also for the average of all fruit. The results of the statistical analysis indicated that the three-hole and four-hole designs are significantly better in cooling the strawberries than the standard crate. The increase in cooling efficiency of the new design is more pronounced at the lower air flow rates. The reason for more efficient cooling with the new designs is probably due to better air flow patterns inside the carton. With the standard carton, the vent hole is cut at the very top edge of the carton. When the air is

forced through the vent hole, it tends to continue through the gap between the top of the baskets and the bottom of the carton immediately above, thus by-passing most of the fruit. With the new designs, the vent holes are more uniformly distributed, forcing more air to flow through the fruit. Before the new designs are adopted, however, tests must be conducted to ensure the strength of the new containers.

The cooling research [1] also established the relationship between cooling rate and air flow rate. Table 2 indicates a large increase in cooling rate when the air flow rate was increased from 1.0×10^{-3} to 2.1×10^{-3} m3/(kg s) (1.0 to 2.0 ft^3/min lb) and a relatively small increase at higher flow rates. Cooling time was shown to also be a function of location of the fruit in the carton with respect to the entering air. The more downstream the location, the longer the cooling time. Table 3 shows the effect of fruit location on cooling time at various air flow rates.

For all air flow rates tested, it took approximately twice as long for the last basket to reach 7/8 cooling as it did for the first basket. Table 4 presents this bed effect in terms of the temperature gradient along the flow path at the time the first pint achieved 7/8 cooling. A temperature gradient of 5 to 6°C (9 to 10.8°F) exists between the first (coldest) pint and the last (hottest) pint. This shows that care must be taken when choosing a fruit to measure the temperature to determine when cooling is completed. In some packinghouses, the operators use the fruit on top of the first basket to guage the degree of cooling because it is the most readily accessible fruit. Table 5 shows the temperature gradient in the strawberries when the top fruit of the first basket has reached 7/8 cooling. A temperature difference of 4°C (7.2°F) exists between the top fruit and the average temperature of basket 1, and 11°C (19.8°F) exists between the top fruit and the average temperature of basket 9.

Room cooling, storage, and shipping

The simplest and slowest cooling method is room cooling, in which the bulk or containerized commodity is placed in a refrigerated room for several hours or days. Air is circulated by the existing fans from the evaporator coil in the room. Vented containers and proper stacking are critical to minimize obstructions to air flow and ensure optimal heat removal. Room cooling alone is satisfactory only for commodities with a low respiration rate, such as mature potatoes and onions. For strawberries it should be used only after precooling for 7/8-cooling time, during short-period storage prior to shipment. Refrigerated trucks should be precooled prior to loading the precooled strawberries. After precooling, top icing of strawberries is not desirable during holding or transport.

Modified atmosphere

Refrigeration is sometimes supplemented with modified atmosphere during transit or storage. With solid loads, the modified atmosphere may be established for the entire transport vehicle. Plastic shrouds are, more commonly, placed over individual pallets equipped with a base that can be sealed. Pallet bags are installed after cooling, usually just before loading for transport. Carbon dioxide (CO_2) is then injected into the package to establish the desired atmosphere. Elevated levels of carbon dioxide (10 to 30%) slow the respiration rate of the fruit and reduce the activity of decay causing organisms, thus extending storage and market life. Carbon dioxide atmospheres of 30% or greater can cause off-flavor. Recent studies [4] indicated that carbon dioxide treatment was of little benefit when storage temperatures were maintained below 5°C (41°F). Therefore, if transit and storage temperatures are maintained below about 2.2°C (36°F) there is little need for the carbon dioxide treatment. Practically speaking, considerable evidence indicates that strawberries are often exposed to temperatures above 4.4°C (40°F) during transport and in these cases the carbon dioxide treatments may be beneficial.

Management guidelines

The following management guidelines or recommendations summarize the important post-harvest information discussed above.

Strawberries should be handled gently at all times to maintain quality since they are so easily bruised. Bruised berries are very susceptible to decay. Anytime a fruit is bruised, the bruised area will discolor. In addition, bruising increases water loss.

Only sound fruit should be shipped, because decay fungi can easily spread throughout each shipping container. Berries without stem caps are particularly perishable. Strict grading should eliminate out-of-grade berries. It important to acknowledge that while proper post-harvest cooling and handling techniques can help maintain product quality, the quality packed can never be improved.

Flats should not be overfilled because stacking will cause crushing. After packing, strawberries - should be kept in the shade and transported to the cooler as soon as possible. The temperature of harvested strawberries in the field can get up to 30°C (86°F), and higher when exposed to sun; and when fruits are allowed to remain at this temperature for 4 hours, marketability drops by at least 40%. Again, very careful handling of the packed strawberries is essential to maintaining quality.

A well-designed forced-air cooler should be maintained at a constant temperature near 0°C (32°F). As noted above, the air flow rate has a definite effect on the cooling rate of strawberries in cartons and new vent hole designs can improve cooling efficiency. A cooling schedule should be developed for the forced-air cooler to maximize efficiency. Use of a schedule allows cooling times to be adjusted based on the initial temperature of the berries and prevents inadequate or excessive precooling resident time.

Temperatures should be measured with a reliable electronic thermometer. Fruit pulp temperatures should be taken prior to precooling and during precooling. Fruit temperatures should be measured on the warm side of the cooler (inside of stack in systems that draw air through the berries; outside of stack in systems which blow air through the berries). Care should be taken in sampling the strawberry temperatures to determine when cooling is completed. There is a large difference in the temperature between the fruit near the air inlet and the fruit in the last basket downstream. Precooler personnel should be trained to use proper strawberry temperature measurement techniques.

Leaving strawberries in the forced-air cooler longer than necessary can lead to undesirable water loss because of rapid air movement. On the other hand, inadequate cooling can lead to rapid deterioration due to high temperatures.

Following cooling, strawberries should be stored in a cold room maintained at 0-1.1°C (32-34°F) for the shortest time possible. The cold room temperature should be colder than the temperature of the berries leaving the precooler. In addition to inefficient use of refrigeration, berries that have been cooled and then allowed to rewarm (causing moisture to condense on them) are extremely susceptible to decay. Humidity as well as temperature must be controlled in storage facilities. If the air inside the storage room is too dry, water will evaporate from the strawberries and they will become soft and shriveled. At a storage room temperature of 0°C (32°F), the relative humidity should be from 90 to 95 percent. Much of the water that evaporates from the fruit condenses on the inside surfaces of the room or is absorbed into packing materials. Under certain atmospheric conditions, it may be necessary to add moisture with a humidification system.

Trailers that are to carry strawberries should be precooled to 1.1°C (34°F) prior to loading. Also, extreme care must be exercised in loading pelletized units to prevent shifting during transit by using strapping and corner boards. Proper bracing is a must for palletized strawberry shipments. The pallet units should be loaded away from the walls to prevent outside heat from transferring directly into the berries.

Conclusion

This publication presents cooling requirements, cooling methods, quality parameters, and management guidelines for maintaining the quality of Florida strawberries. Studies conducted to establish the relationship between cooling rate and air flow rate and the effects of new vent hole designs on cooling rates of strawberries are discussed. Management guidelines or recommendations to the packinghouse operators concerning possible system performance improvements are presented, such as increasing resident time within the forced-air precooler to achieve better cooling or lowering the cold room temperature to prevent warming of precooled strawberries. To continue delivery of a high-quality

product, growers need to grow and harvest high-quality strawberries, and afterharvest product quality must be maintained with the right precooling, handling, and storage methods.

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Table 1.

[2][30-1.1]*1/2 = 14.5	([86-34]*1/2 = 26)
[3][30-14.5] = 15.5	([86-26] = 60)
[4][30-1.1]*7/8 = 25.3	([86-34]*7/8 = 45.5)
[5][30-25.3] = 4.7	([86 - 45.5] = 40.5)

Table 2.

Table 1.Vent-hole sizes and percent opening for different designs.

Configuration	Diameter, m (inch)	% Opening
Standard	-	14.0
3-hole	38.1×10^{-3}(1.5)	13.5
4-hole	38.1×10^{-3}(1.5)	18.0
7-hole	25.4×10^{-3}(1.0)	14.0

Table 3.

Table 2. Seven-eighths cooling time (minutes) as function of vent hole desings (basket number 9, and average of all fruit).

Vent hole configuration								
Air flow rate	std.hole		3 holes		4 holes		7 holes	
m^3/s kg(ft^3/lb min)	last basket	average all fruit	last basket	average all fruit	last basket	average all fruit	last basket	average all fruit
$1.04x10^{-3}$(1.0)	160	122	132	98	136	100	136	100
$2.08x10^{-3}$(2.0)	82	64	76	52	72	50	82	62
$4.16x13^{-3}$(4.0)	74	52	70	50	68	46	68	48
$6.24x10^{-3}$(6.0)	52	34	50	34	46	32	46	32

Table 4.

Table 3. Cooling time as function of fruit location. There were nine baskets along the flow path.

Air flow rates		7/8-Cooling time (minutes)			
m^3/kg s	ft^3/min lb	Basket 1	Basket 3	Basket 6	Basket 9
$1.04x10^{-3}$	(1.0)	84	102	134	160
$2.08x10^{-3}$	(2.0)	48	56	72	82

Table 4.

4.16×10^{-3}	(4.0)	38	46	58	74
6.24×10^{-3}	(6.0)	28	28	34	52

Table 5.

Table 4. Temperature distribution at the time basket 1 reaches 7/8-cooling time for standard cartons.					
Air flow rates	Temperature, ¡C (¡F)				
m^3/kg s	ft^3/lb min				
		Basket 1	Basket 5	Basket 9	Mass Avg. (3 cartons)
1.04×10^{-3}	(1.0)	4.7 (40.5)	5.6 (42.1)	10.6 (51.1)	7.3 (45.1)
2.08×10^{-3}	(2.0)	4.7 (40.5)	6.5 (43.7)	10.2 (50.4)	6.7 (44.1)
4.16×10^{-3}	(4.0)	4.7 (40.5)	6.7 (44.1)	11.1 (52.0)	7.1 (44.8)
6.24×10^{-3}	(4.4)	4.4 (40.5)	5.0 (41.0)	10.7 (51.3)	5.9 (42.6)