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Cooling Florida Sweet Corn[1]

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The sugar content of standard sweet corn cultivars, which largely determines quality, decreases rapidly at normal temperatures [1][3]. Loss of tenderness and sweetness are not acceptable to consumers. New supersweet cultivars with twice the sugar content of standard cultivars lose their sweetness more slowly during marketing and have improved consumer satisfaction. However, proper temperature management is important even with the supersweet corn varieties [2, 3]. Proper temperature management of sweet corn begins with precooling (rapid removal of field heat) from field temperatures which can be above 30°C (86°F). Rapid removal of field heat is critical to retard deterioration of sweet corn. The recommendation for maximum quality retention of sweet corn is precooling to near 0°C (32°F) within 1 hour of harvest and maintaining at 0°C (32°F) throughout the marketing channels [5]. Commercial sweet corn operations in Florida rarely achieve this ideal cooling criterion due to various factors, including volume of corn handled, cooling and handling equipment availability and capability, economics, energy, and market conditions.

Florida leads the nation in sweet corn production with an average annual value of $69.7 million for the last 5 years [4]. Sweet corn yields in Florida averaged 219 crates per acre with 11.4 million crates packed from 51.9 thousand acres, with a season average f.o.b. of $6.13 per crate over the last 5 years.

Sweet corn 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 sweet corn in Florida is hydrocooled or vacuum cooled in wooden crates. However, a recent commercial effort was undertaken to utilize slush icing (or package icing) for precooling sweet corn in wax-impregnated fiberboard cartons. Room cooling of sweet corn is too slow to be an acceptable precooling method, and refrigerated trucks cannot remove field heat during transit due to inadequate refrigeration capacity.

This publication presents cooling requirements, cooling methods, quality parameters, and management guidelines for maintaining the quality of Florida sweet corn during handling and shipping operations. Studies conducted at various commercial sweet corn precooling operations from Homestead to Alachua over several growing seasons are discussed. The results of sweet corn quality evaluation judged from a consumer perspective are also presented. Initial quality evaluations were compared to the quality after precooling and postharvest handling to simulate the sweet corn condition observed by the consumer. Recommendations are presented for packinghouse operators concerning improvements possible in system performance, such as increasing residence time within a hydrocooler to achieve better cooling or lowering the cold room temperature to prevent warming of vacuum-cooled corn.

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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 [6].

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 cultivar, maturity or stage of ripeness, injuries, temperature, and other stress related factors. Sweet corn has a high respiration rate, 40 mg CO_2/kg-h (8,900 Btu per ton per day) at 0°C (32°F) [5]. The major determinant 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 [5]. For example, the respiration of sweet corn at 10°C (50°F) is 112 mg $C0_2$/kg-h (24,600 Btu per ton per day), almost three times greater than at 0°C (32°F). Therefore, sweet corn must be rapidly precooled to slow its metabolism (physiological deterioration) in order to provide maximum quality and storage life for shipping and handling operations.

Sweet corn is not a chilling-sensitive crop (crops which must be stored at temperatures generally above 10°C (50°F) to prevent physiological damage). Therefore, it 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 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 [8] that 7/8 of the difference between the pulp temperature and the cooling medium temperature (7/8-cooling time) 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 corn is harvested at 30°C (86°F) and cooled in a hydrocooler with a water temperature of 0°C (32°F), the half-cooling time would be the time required to remove 15°C (27°F)[2] or for the corn to be cooled to 15°C (59°F)[3] . For the same situation, the 7/8-cooling time would be the time required to remove 26°C (47°F)[4] or for the corn to be cooled to 4°C (39°F)[5]. By developing a precooling schedule [8], the 7/8 cooling time could be established. Therefore, after precooling for a time period equal to the 7/8-cooling time or when the pulp temperature reached 4°C (39°F), the corn would be removed from the precooler and moved to cold storage for additional cooling to 0°C (32°F).

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 two factors: cooling medium temperature, and contact between cooling medium and product. In addition, the product must remain in the precooler for sufficient time to remove the heat (7/8-cooling time) to achieve maximum cool. 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 residence time for precooling, while at the same time not slowing subsequent packing and/or handling operations. The cooling medium (air, water, crushed ice) must be maintained at a constant temperature throughout the

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[2] [30 - 0] * 1/2 = 15 ([86 - 32] * 1/2 = 27)
[3] [30 - 15] = 15 ([86 - 27] = 59)
[4] [30 - 0] * 7/8=26 ([86 - 32] * 7/8 = 47)
[5] [30 - 26] = 4 ([86 - 47] = 39)

cooling period. If the refrigeration system is undersized for the amount 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 sweet corn. Inappropriately designed containers can markedly reduce flow of the cooling medium.

The cooling rate is not only dependent upon cooling-medium temperature and contact with the commodity, it is also dependent on the cooling method employed.

Vacuum cooling

Vacuum cooling (Figure 1) is the most rapid method of precooling sweet corn, although it is most efficient for commodities with a high surface-to-volume ratio such as leafy crops. This method is based on the principle that the boiling point of water lowers as atmospheric pressure is reduced. Cooling is achieved on a large scale by reducing the atmospheric pressure inside a large, air-tight, strongly constructed steel vacuum chamber (tube) containing the sweet corn packed in containers and pelletized. The pressure in the chamber is reduced, which reduces the pressure of water vapor in the chamber. When the water vapor pressure in the chamber is reduced below that in the product's intercellular spaces, water will evaporate from the product resulting in cooling. The water on the product surface boils at the desired precooling temperature, usually near 0°C (32°F) wet bulb temperature when the chamber pressure reaches 4.6 mm (0.18 inches) mercury absolute pressure. Water evaporating from the surface removes field heat from the product and condenses on evaporator coils within the vacuum tube. Evaporator coils increase cooling efficiency by removing water vapor from the air, permitting faster evaporation of the water from the surface of the product. Crated corn can be vacuum cooled from 27.3°C (81°F) to 3.4°C (38°F) in about 50 minutes [9].

Figure 1. Vacuum cooler chambers and palletized crates of sweet corn.

Measurement of sweet corn pulp temperature in the vacuum cooler is important. A gauge that measures absolute pressure in the chamber gives a direct indication of the boiling temperature of water in the chamber, and is probably the most reliable guide to managing a vacuum cooler. A remote temperature probe inserted into an ear of corn and connected to an indicator outside the chamber will indicate cooling of exposed corn, but corn in the interior of the load may be considerably warmer, particularly if air is present. The value of a wet-bulb thermometer (which represents the boiling point of water in a vacuum) is limited by air leaks into the system which may raise the actual boiling point of the water considerably above the wet-bulb reading.

Packed corn can be cooled quickly and uniformly in large loads by this method, but container walls or other barriers can seriously slow cooling by retarding water vapor escaping from the corn. Failure to properly wet the corn before or during the vacuum cooling cycle can result in a 1 percent moisture loss for each 6°C (11°F) change in corn temperature [7]; therefore, denting of kernels may occur. The vacuum-cooled sweet corn must be moved quickly to a cold room, or rapid rewarming will occur.

Vacuum coolers are costly to purchase and require skilled operators. To be economically feasible, there must be a large daily and annual output of cooled produce. Thus, a vacuum cooler must either be located close to a long-season production area or made portable so it can be moved to locations where there is such production.

Hydrocooling

The use of cold water to quickly cool produce is an old and effective method used for cooling a wide range of fruits and vegetables in bins or in bulk before packing or in containers after packing. However, its use for packed commodities has limitations because of the difficulty of achieving sufficient water flow through the containers, and because the containers must be water-tolerant. Hydrocooling by showering or immersion in water is the most common precooling method for sweet corn. Hydrocooling removes heat at a slower rate than vacuum cooling. The heat capacity of refrigerated water is greater than that for air, which means that a given volume of water can remove more heat than the same volume of air at the same temperature.

Hydrocooling removes no water from the produce. and may even revive slightly wilted produce. Effectiveness of this cooling method depends upon low and constant water temperature 0-1°C (32-34°F), maximum surface contact of water with corn, and sufficient time for heat removal. Hydrocooling corn in bulk is more efficient than hydrocooling crated corn due to improved contact between water and corn. However, bulk handling may not fit into the management scheme and some rewarming of the corn will occur during the subsequent packing operations. Crated corn on pallets may take over an hour in a hydrocooler to cool from 28°C (82°F) to 7°C (45°F) using 4°C (40°F) water [9].

Figure 2. Conveyor hydrocooler precooling palletized crates of sweet corn.

Several types of hydrocoolers are used for sweet corn in Florida. Conveyor hydrocoolers are the most common type (Figure 2). In this type, corn in bulk, individual containers, or in containers on pallets stacked four or five layers high, is carried on a conveyor through a shower of water. Large overhead spray nozzles must be capable of discharging a large volume of water over the pelletized crates to efficiently remove heat. If the mass of produce is deep (a foot or more) the water may "channel" (pour through larger openings where least resistance to flow is encountered) and come in contact with only part of the lower surfaces. Channeling may be avoided by providing a heavy shower over a shallow depth of produce, or by proportioning the shower and the drainage from the bottom of containers so that the containers will be partly or entirely filled with water. Drainage must be sufficient to keep the water in the containers moving, and to remove all water before containers leave the hydrocooler. Corn toward the center of the pallet is most difficult to adequately cool.

The length of the hydrocooler conveyor is important and must not be underestimated. If, for example, a hydrocooler takes 45 minutes to cool sweet corn from 34°C (94°F) to 4°C (40°F) with 1°C (34°F) water, the hydrocooler must be large enough to hold, at one time, the maximum quantity of corn that will be loaded into it in 45 minutes. Also, for greater cooling efficiency, the refrigeration capacity must be sufficient to maintain a constant water temperature of 1°C (34°F), regardless of the initial corn pulp temperature.

Many commercial hydrocoolers are inefficient simply because they lack insulation. Tests have shown that less than half of the refrigeration supplied to most conveyor-type hydrocoolers is used to cool the produce - the rest is lost through insufficient insulation [7].

The room-type or "batch" hydrocooler has no conveyors and so is more easily insulated. Containers to be cooled are stacked in rooms, normally pelletized, and may be left there in temporary storage. At least two rooms are usually provided, so that one can be precooling while the other is emptied and filled. Even though only half the floor space is used at any one time for precooling, floor area in this type of operation is much less expensive than floor area in a conveyor operation, and the total space occupied is not necessarily more than for the latter. Overhead spray nozzles capable of discharging a large volume of water over the pelletized crates are located in the roof of the cold room to efficiently remove heat. The system should be designed so that only nozzles located above the product requiring cooling are discharging cold water. The cooling water returns to the refrigeration unit through drains in the floor.

Sanitation of the hydrocooling water is critical, since it is first refrigerated, drenched over the product, collected, recooled, and drenched again over the product. Decay organisms present on a few vegetables can accumulate in the water, inoculating subsequent product being hydrocooled. Commodities which are hydrocooled must be resistant to contact with waterborne pathogens and be able to withstand the force of the water drench.

Potential limitations of hydrocooling must also be considered. When the hydrocooler is operating at capacity, arriving warm produce must remain at ambient temperatures to await cooling. Attempts to shorten the cooling (residence) time to increase throughput of sweet corn will result in unsatisfactory cooling. Furthermore, when cooling is completed, the product must be moved quickly to a cold room, or rapid rewarming will occur. Cooling efficiency may be low unless the hydrocooler is operated continuously at maximum capacity or is inside a cold room or insulated enclosure. Shower-pan holes must be cleaned daily to avoid plugging that can cause uneven water flow over the product.

Slush-ice cooling

Slush-icing (liquid-icing), an improved form of package-icing, is another method to precool sweet corn. A slurry of refrigerated water and finely chopped ice can be drenched over either bulk or containerized produce. This slush-ice method is becoming more widely adopted for commodities tolerant of direct contact with water and, as noted above, has been used commercially to precool sweet corn in Florida (Figure 3). The water acts as a carrier for the ice so that the resulting slush can be pumped into a packed container. The rapidly flowing slush causes the product in the container to float momentarily and distributes the ice throughout the container, achieving better ice/product contact when the water drains out of the container vents. As the product settles in the container, the ice encases the individual items by filling air voids (Figure 4), thus providing good contact for field heat removal. The residual ice continues the cooling process and also maintains high relative humidity within the container. Slush-icing is a somewhat slower cooling method than vacuum cooling and hydrocooling. Corn in wax-impregnated fiberboard boxes which was placed in a 8.4°C (47.5°F) cold storage room (which is too warm) after slush ice cooled from 23°C (74°F) to 5°C (42°F) in an hour [9].

Skilled management is required to control the slurry mixture and insure adequate ice remains to precool the corn. It is important to quickly store the cartons in a cold room after precooling to insure no reheating of cartons.

Slush-icing requires use of more expensive, water-tolerant shipping containers (wax-impregnated fiberboard boxes) and specialized slurry mixing and pumping equipment, as well as ice-making and handling equipment. The systems used in Florida were batch systems and some packinghouse operators question the ability of slush-ice precooling for large volume operations. However, equipment is commercially available for automatically icing pallet loads of packed cartons.

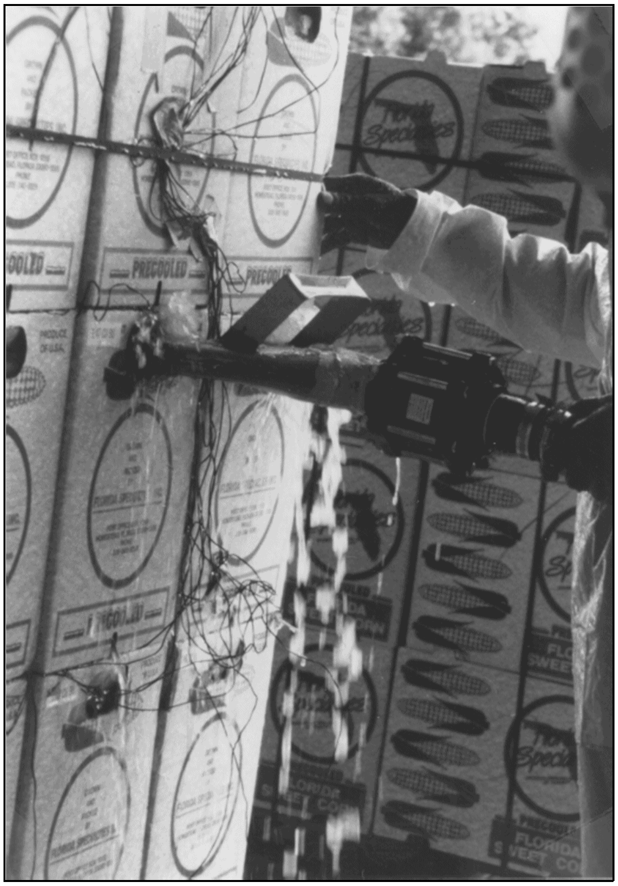

Figure 3. Injection of water-ice slurry into carton through the hand hole slush-ice precooling of sweet corn.

Figure 4. Carton cut open showing ice well-dispersed among the ears of corn after slush-icing.

Table 1. Commercial sweet corn precooling studies.

		Type of precooling			
Test number	Location	Slush ice	Hydrocooling	Vacuum	Quality evaluated
1	Homestead	3-Pallet^{z}			
2	Homestead	3-Pallet^{z}			
3	Zellwood			Pallet^{z}	
4	Alachua		Short Tunnel^{z}		
5	Homestead	1-Pallet^{y}	Single Crates^{x}		Before/After^{w}
6	Zellwood	Modified^{y}	Long Tunnel^{z,v}	Pallet^{z}	Before/After

^{z}Pallet ^{y}Carton ^{x}Crate ^{w}Commercial Shipment ^{v}Pallet cooling data lost

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 is satisfactory only for commodities with a low respiration rate, such as mature potatoes and onions. For sweet corn 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 sweet corn. After precooling, top icing of wirebound-crated corn is desirable during holding or transport to continue cooling, remove heat of respiration, and keep the husks green and fresh. The ice should be wind-rowed to prevent interference with air movement.

Management guidelines

Sweet corn precooling experiments [9] which illustrate important management points are outlined in Table 1. Tests 1 through 4 were individual evaluations for indirect comparisons of precooling methods while Tests 5 and 6 were designed for direct comparison of precooling methods. Various supersweet sweet corn varieties were used depending on the cooperator and test date.

Standard wood crates were used for the hydrocooling and vacuum cooling tests, while specially-designed, cascaded waxed, corrugated cartons were used for the slush-ice tests. Slush-ice precooling in Tests 1 and 2 was accomplished using a commercial system with a three-pallet capacity: one waiting injection; one being injected; and one draining water. Two men operated nozzles (Figure 3), one on each side of the pallet, injecting a water-ice slurry into two cartons at a time through the hand holes, and working from the top to the bottom of the pallet. Slushing required approximately two minutes while draining and movement to cold storage required an additional two minutes. Six instrumented cartons were placed on a pallet of corn and slushed in the same manner pallets were normally slushed. The slush ice precooling in Test 5 was accomplished with a smaller, one-pallet commercial slush system. During the test, only one slush nozzle was used. Other system problems with ice delivery increased the time required to slush and only the instrumented cartons were slushed before movement to cold storage. The slush-ice precooling in Test 6 was not possible with the slush system at the test location. To make a direct comparison between precooling methods, a modified slush-ice procedure was devised. Crushed ice was mixed with water in a large tub and then poured into the opened top of the waxed cartons containing the corn and sensors.

The Test 4 hydrocooling was conducted in a two-tunnel pallet (conveyor) hydrocooler (Figure 2), with 5°C (41°F) refrigerated water continuously showering down from an overhead perforated storage pan while the pallets were slowly pulled through the tunnels by cleated chain drives. The hydrocooler in Test 5 showered refrigerated water (1°C (34°F)) from an overhead perforated storage pan over individual crates of sweet corn conveyed five abreast through the hydrocooler on a slowly moving belt. The hydrocooling in Test 6 was also a two-tunnel pallet hydrocooler similar to, but much longer than, the Test 4 hydrocooler.

The same vacuum cooler was used in Tests 3 and 6 (Figure 1). The pallets of corn were moved into the vacuum tube on long wagons and sprayed with water. The tube was sealed and sufficient vacuum (5.2 mm (0.2 inches) mercury absolute pressure) was applied to cool the corn to 3°C (38°F). After breaking the vacuum, and a brief rewetting and draining period, the wagon of pallets was pulled from the tube and exposed to ambient conditions until each pallet was removed from the wagon by forklift and transferred to a 7°C (45°F) cold storage.

Test 5 involved a commercial shipment from Homestead to Gainesville via Jacksonville. During Test 5, the corn was transported from the packing-house cold storage to the cold storage of a shipper, then transported to Jacksonville by commercial refrigerated trailer and placed in the receiver's cold storage, then transported (air conditioned vehicle) to Gainesville (approximately 116 km (72 miles)), and stored at 5°C (41°F) for a total of ten days after harvest. During Test 6, the corn from the hydrocooler was transported back to the vacuum cooler packinghouse and stored overnight with the vacuum-cooled and modified slush ice-precooled corn. All three precooling treatments were transported (air conditioned vehicle) to Orlando (approximately 30 km (19 miles)) and stored at 5°C (41°F) for a total of 10 days after harvest.

Treatment conditions and final temperatures for slush-ice, hydrocooling, and vacuum precooling are summarized (Table 2). The first entry indicates corn with an initial average shank temperature of 23.6°C (74.5°F) was precooled using the 3-pallet slush-ice unit (Test 1), placed in a 1.8°C (35.2°F) cold room for 1.8 hours, and achieved a final average shank temperature of 5.7°C (42.3°F). In addition, the hydrocooling and vacuum cooling entries indicate the precooling time and average shank temperature after precooling. The hydrocooling entries also provide the mean cooling water temperature.

The concept of percent cooling is used to compare different types of precoolers. The percent cooling is based on the ratio of the temperature difference between the initial and final corn temperature, to the temperature difference between the initial and ideal corn temperature, 0°C (32°F). The time to achieve 50 and 75% for all precooling tests is provided in Table 3. In terms of the definitions above, when the cooling medium temperature equals the ideal temperature, half cooling represents 50% cooling, while 7/8 cooling equates to 88% cooling. For example, if corn with an initial temperature of 28°C (82.4°F) is cooled for 30 minutes using 0°C (32°F) to a temperature of 14°C (57.2°F), the percent cooling would be [(28-14)/ (28-0)] * 100 = 50%[6] and the half cooling time would be 30 minutes.

The three-pallet slush-ice Tests 1 and 2 indicated very satisfactory performance of the slush-ice unit (Table 3, Figure 5a, Figure 5b). A carton of corn slush iced during Test 1 was cut open to reveal 11 kg (24 lb) of ice well dispersed among the ears of corn (Figure 4). After initial precooling, ice remained for additional cooling and could serve as insurance in the event of a break in the cool environment during shipment. The cooperator indicated his receivers were pleased when cartons were opened upon receipt and ice was still present. The one-pallet slush-ice unit used during Test 5 did not perform as well as the first unit (Table 3, Figure 5a, Figure 5b). The modified slush ice procedure results in Test 6 were similar to Test 5 (Table 3, Figure 5a, Figure 5b). The management requirements for slush-icing are similar to that needed for vacuum cooling but with more variables to consider (uniform packing, rapid handling, thorough injection, proper water-ice slurry concentration, sufficient ice supply, proper injection pressure, system plugging, etc.).

The short-tunnel hydrocooler (Test 4) involved a moderate cooling water temperature and short precooling time (Table 2), resulting in less cooling than the three commercial slush ice tests (Table 3, Figure 5a, Figure 5b, and Figure 6a, Figure 6b). Both reduced water temperature and increased precooling time would improve the cooling performance. The cooling water temperature for the single-crate hydrocooler in Test 5 was ideal (Table 2) and the product was precooled in single crates rather than on pallets, which would increase the cooling rate. However, the inadequate precooling time (Table 2) resulted in a cooling performance less than that of the three commercial slush-ice tests and the short-tunnel hydrocooling system of Test 4 (Table 3, Figure 5a, Figure 5b, and Figure 6a, Figure 6b). An increase in the precooling time would provide greater cooling. The cooling water temperature for the long-tunnel hydrocooler in Test 6 was moderate but the precooling time was ideal (Table 2). The shank temperature of one ear of corn in one test crate was measured before and after precooling using a hand-held thermometer. A decrease in the cooling water temperature would improve the cooling rate and could allow shorter cooling time with increased throughout. With adjustments to operating conditions, this system also has the potential to be an outstanding hydrocooling system (Table 3, Figure 6a, Figure 6b).

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[6] [(82.4 - 57.2) / (82.4 - 32)] * 100 = 50%

Table 2. Summary of treatment condition for cooling sweet corn.

	Initial shank temp. (°C)				Mean Cold store air temp. (°C)	Room cool (hr)	Final shank temp. (°C)
Slush-ice							
Test 1	23.6				8.6	1.8	5.7
Test 2	18.7				3.3	17.2	0.7
Test 5	21.7				7.0[z]	22.6[z]	5.0[y]
Test 6	26.7				6.4	19.2	5.5
	Initial shank temp. (°C)	Precool (min)	Mean water temp. (°C)	After Cooling Shank temp. (°C)	Cold stor. air temp.	Room cool (hr)	Final shank temp. (°C)
Hydrocooling							
Test 4	27.3	17	5.0	19.3	9.1	21.6	8.2
Test 5	20.5	13	1.0	17.3	7.0	22.9	9.0
Test 6	28.0	60	4.7	7.2	6.4	19.2	6.8
	Initial shank temp. (°C)	Precool (min)		Shank temp.	Cold stor. air temp.	Room cool (hr)	Final shank temp.
Vacuum cooling							
Test 3	26.5	52		4.8	7.0	0.8	5.6
Test 6	27.3	53		3.4	6.4	19.2	6.8
[z] during shipment [y] minimum achieved followed by warming							

Table 3. Summary of sweet corn precooling tests.

	Time to achieve cooling (minutes)	
Method	50%	75%
Slush-ice		
Test 1, 3-pallet	41	103
Test 2, 3-pallet	52	157
Test 5, 1-pallet	124	682
Test 6, Modified	135	669
Hydrocooling		
Test 4, Short tunnel	111	1231 (70%)[y]
Test 5, Single crates	228	1914 (60%)[y]
Test 6, Long tunnel	34[x]	67[x]
Vacuum cooling		
Test 3	31	46
Test 6	27	39
[y] 75% not achieved during test		
[x] lost data; cooling time during test from intial and final temperatures measured with hand-held thermometer.		

The vacuum cooling tests (Tests 3 and 6) produced similar results during different harvest seasons (Table 2, Figure 7a, Figure 7b). Vacuum cooling provided the most rapid cooling rate of all the methods (Table 3). The vacuum-cooled corn actually was warmed after placement in the cold storage room (Table 2). Reducing the cold room temperature would decrease the loss of precooling benefits. Movement directly from the vacuum cooler to the cold storage room, rather than exposure to ambient conditions, is very desirable.

The results of the commercial shipping Test 5 (Figure 8, Figure 9) illustrate the importance of maintaining the storage temperature after precooling. During transport by refrigerated trailer to Jacksonville at 5°C (41°F), the hydrocooled corn reached a low temperature (average shank temperature for three crates) of about 10°C (50°F) (Figure 8), while the slush-ice cooled corn continued to cool below 5°C (41.0°F) (Figure 9). During unrefrigerated transport of the crates and cartons from Jacksonville to Gainesville (2.5 to 3 hours), the hydrocooled corn cob temperatures rose to about 14°C (57°F) (Figure 8), while the ice melted in the slush-iced corn and the cob temperatures rose to about 9°C (48°F) (Figure 9). This unrefrigerated transport may have reduced potential quality differences between these two precooling treatments. When placed in 5°C (41°F) cold storage in Gainesville, the corn in slush ice cartons cooled more slowly than the hydrocooled corn in crates (Figure 8, Figure 9).

The comparative Test 6 (Figure 10a, Figure10b) lacked complete data on hydrocooling although the operation appeared to be satisfactory. The modified slush-ice treatment performed poorly, indicating the importance of injecting sufficient water-ice mixture of proper consistency into the cartons. Unrefrigerated transport of the precooled corn (after overnight cold room storage) occurred between Zellwood and Orlando prior to additional 5°C (41°F) cold storage.

Quality parameters

Tests 5 and 6 included initial and final quality evaluations. Samples for measurement of moisture, dry matter, pericarp, and sugar content of the sweet corn kernels were taken initially, and after up to 10 days storage at 5°C (41°F). Ratings of appearance quality and eating quality after storage were made on the same six ears per treatment replicate used for the measurements described above. Appearance ratings were given for husk color, husk drying, silk appearance and kernel appearance; eating quality ratings were given for kernel taste and kernel texture. The ears were rated on a 1 to 5 scale with 1 = poorest quality and 5 = best quality in each case.

Comparing hydrocooling to slush-ice precooling in Test 5, there were no significant changes in moisture, dry matter or pericarp contents during storage (data not shown). Sugar content decreased 30 percent during 10 days of storage at 5°C (41°F), but there was no significant difference between the two precooling treatments (data not shown). Husk color was better and there was less drying in slush-iced sweet corn after 2 days of storage but there was no difference between the treatments after 10 days (Table 4). Silk appearance showed no treatment effect but kernel appearance was better after 10 days of storage in the slush-ice treatment (Table 4).

When hydrocooling, slush-ice, and vacuum cooling were compared (Test 6), moisture content was lower and dry matter content higher in the vacuum-cooled sweet corn after storage for 5 or 10 days at 5°C (41°F) (Table 5). Pericarp content increased during storage and sugar content decreased in vacuum-cooled and slush-iced sweet corn but did not change significantly in hydrocooled sweet corn (Table 5). Silk appearance was best in slush-iced sweet corn, but husk color, husk drying, kernel appearance and kernel taste were not affected by the three precooling treatments (Table 6). Kernel texture ratings were lower in vacuum-cooled sweet corn and higher in slush-iced sweet corn.

The precooling methods tested resulted in relatively minor differences in quality of the sweet corn. Even though the vacuum-cooled sweet corn was drenched with water prior to and after cooling, there was still some indication of kernel drying. The husks, however, appeared to remain in good condition. Although hydrocooling had no effect on pericarp content or sugar level compared to slush ice in Test 5, the more thorough hydrocooling treatment performed in Test 6 resulted in lower pericarp and higher sugar levels. Slush-ice precooling appears to be capable of producing sweet corn that has quality comparable to hydrocooling and vacuum cooling. The greatest potential for slush-icing may be as a supplement to either hydrocooling or vacuum cooling where the ice may act as a buffer against suboptimal temperature and humidity conditions encountered during handling.

Table 4. Appearance ratings for precooled sweet corn after 2 and 10 days of storage at 5°C (41.0°F) (Test 5).

		Appearance ratings[z]			
Storage time (days)	Precool method	Husk color (1-5)	Husk drying (1-5)	Silk app. (1-5)	Kernel app. (1-5)
2	Slush-ice	5.0a[y]	4.8a	3.9a	5.0a
	Hydrocool	3.6b	3.6b	3.7a	5.0a
10	Slush-ice	2.5a	2.7a	2.6a	4.4a
	Hydrocool	2.7a	2.3a	2.2a	3.2a

[z] Based on ratings from 6 ears per container, 3 containers per treatment: husk color, 1=yellow, 5=green; husk drying, 1=dry, 5=fresh, turgid; silk, 1=limp, collapsed, 5=fresh, turgid; kernels, 1=indented, dull, 5=turgid, shiny.

[y] Pairs of means within storage times followed by the same letter are not significantly different by t-test (P>0.05).

Table 5. Analysis of sweet corn kernels prior to precooling and after 5 and 10 days of storage at 5°C (41.0°F) (Test 6).

		Kernel analysis			
Storage time (days)	Precool method	Moisture content (%fr. wt.)	Dry matter (% fr. wt.)	Pericarp content (% dry wt.)	Sugar content (% fr. wt.)
0	-	74.57	25.43	11.83	11.66
5	Vacuum	75.17	24.83	10.73	11.61
	Slush-ice	75.62	24.38	10.98	10.88
	Hydrocool	75.57	24.43	11.95	10.51
10	Vacuum	74.83	25.17	13.21	9.64
	Slush-ice	76.12	23.88	13.20	8.99
	Hydrocool	76.26	23.74	12.46	10.99
LSD (0.05)		0.37	0.37	0.78	1.11

Table 6. Quality ratings of precooled sweet corn after 10 days of storage at 5°C (41.0°F) (Test 6).

		Appearance quality[z]			Eating quality[y]	
Husk color (1-5)	Husk drying (1-5)	Silk app. (1-5)	Kernel app. (1-5)	Kernel taste (1-5)	Kernel texture (1-5)	Precool method
Vacuum	2.7a[x]	2.7a	1.8c	1.7a	3.7a	2.9b
Slush-ice	2.8a	2.7a	3.0a	2.3a	3.9a	3.5a
Hydrocool	2.6a	2.8a	2.4b	2.3a	3.7a	3.2ab

[z] Ratings as in Table 4.

[y] Based on ratings from 6 ears per container, 3 conatiners per treatment: kernel taste, 1=bland, watery or starchy, 5=fresh, sweet corn taste; kernel texture, 1=flaccid, tough, 5=turgid, tender.

[x] Means in columns followed by the same letter are not significantly different by DMRT (P>0.05)

Conclusion

This publication presented cooling requirements, cooling methods, quality parameters, and management guidelines for maintaining the quality of Florida sweet corn. Studies conducted at various commercial sweet corn precooling operations were discussed. Recommendations to the packinghouse operators concerning possible system performance improvements were presented, such as increasing residence time within a hydrocooler to achieve better cooling or lowering the cold room temperature to prevent warming of vacuum-cooled corn. The results of sweet corn quality evaluations judged from a consumer perspective were also presented.

The importance of precooling and proper temperature management during subsequent handling of sweet corn was illustrated. The three precooling methods discussed are valuable first steps in proper temperature management for sweet corn. However, each has advantages and disadvantages. Slush-ice cooling appears to be a viable precooling alternative for precooling sweet corn. Results from studies of precooling operations at commercial packing houses indicate that most are doing a good job of precooling. The performance of existing systems can be improved if the operators make adjustments suggested in this study. Additional study is needed and planned to provide more thorough advice to the packinghouse precooling operators. In addition to the evaluation of cooling efficiency, more information is needed for economic and energy analysis in order to compare the performance of various commercial precoolers.

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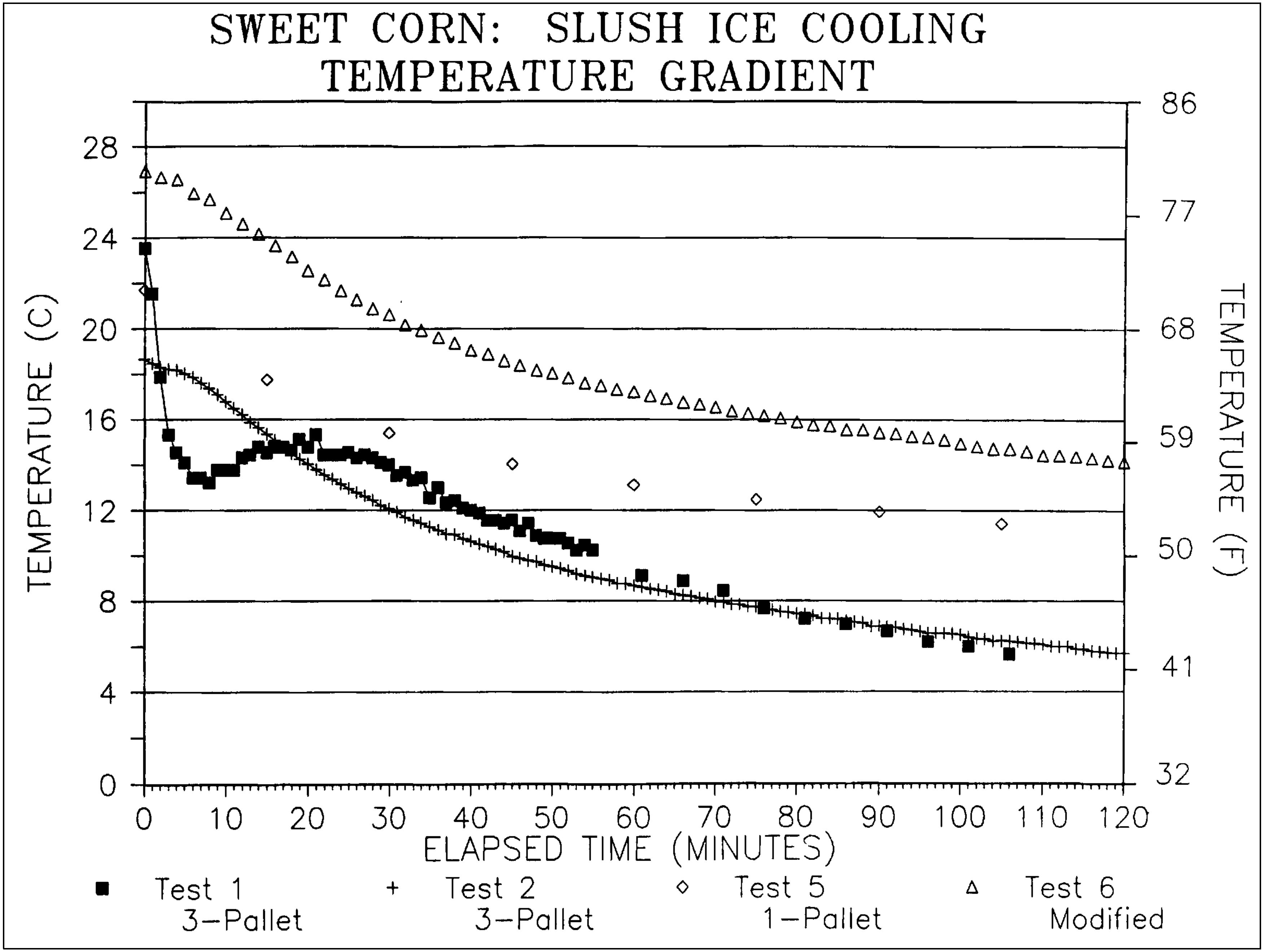

Figure 5A. Time-temperature relationships for sweet corn precooled using slush-ice (Tests 1, 2, 5, and 6).

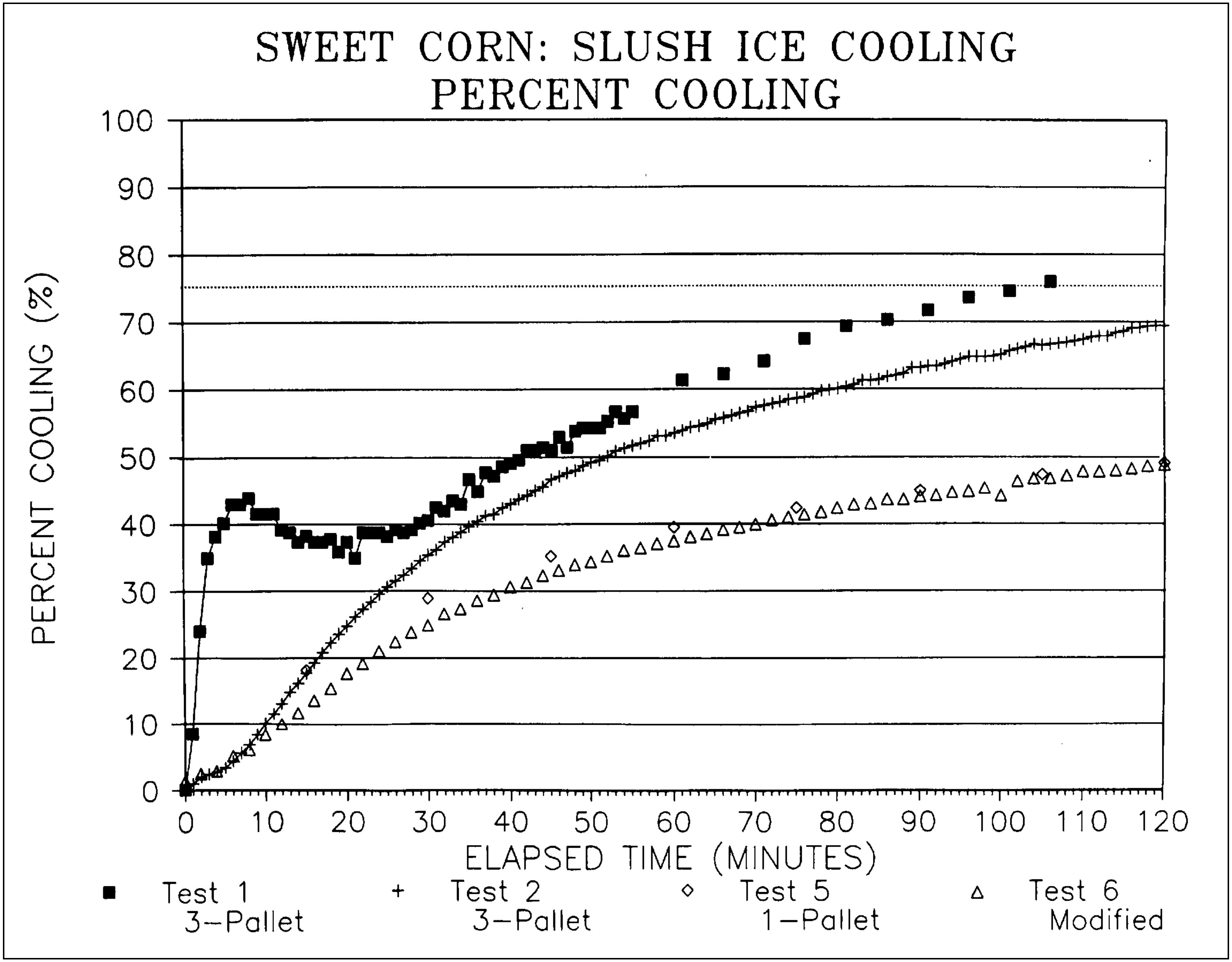

Figure 5B. Percent of initial temperature cooling curves for slush-ice precooling (Test 1, 2, 5, and 6).

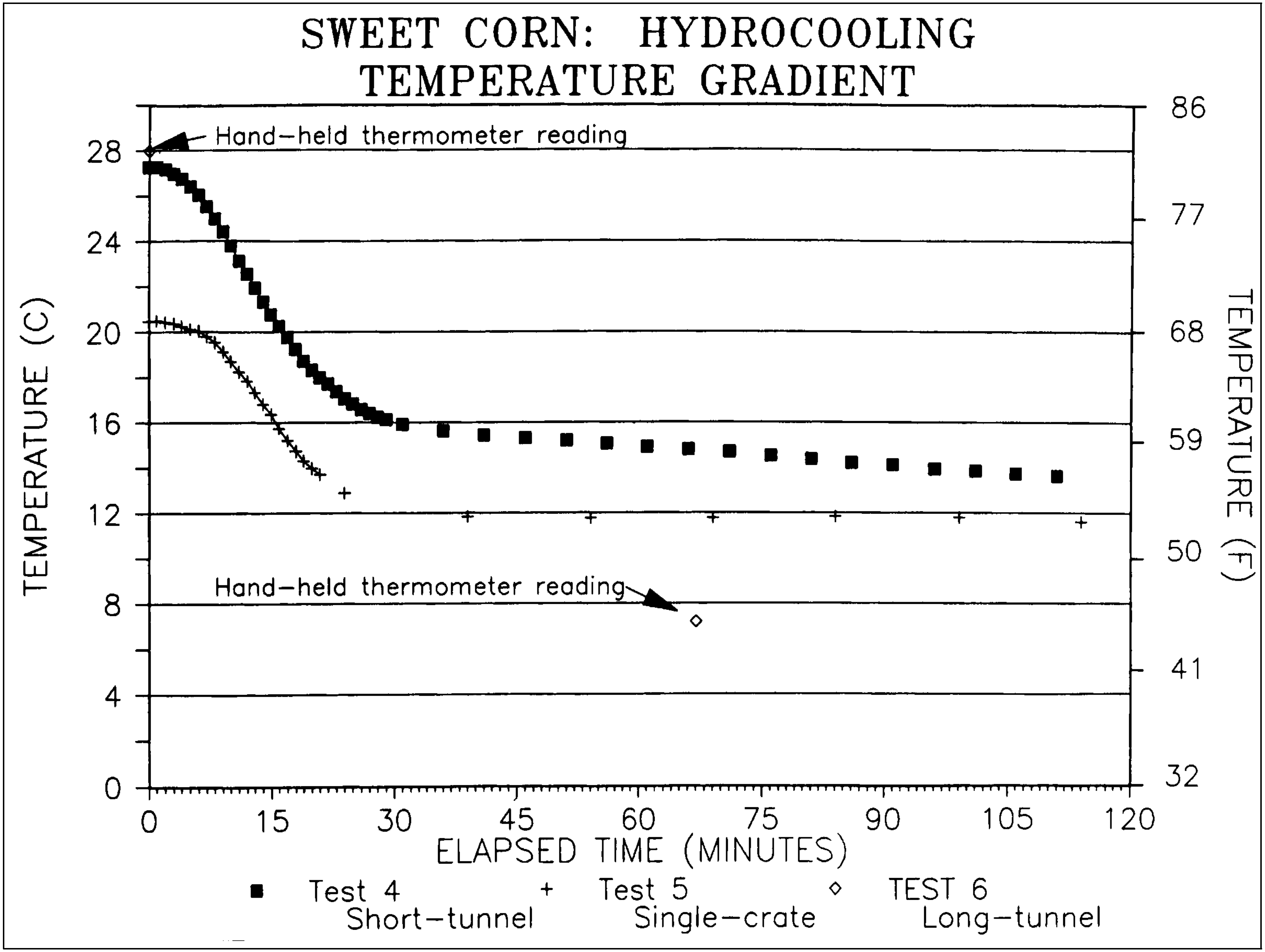

Figure 6A. Time-temperature relationships for sweet corn precooled using hydrocooling (Tests 4, 5, and 6).

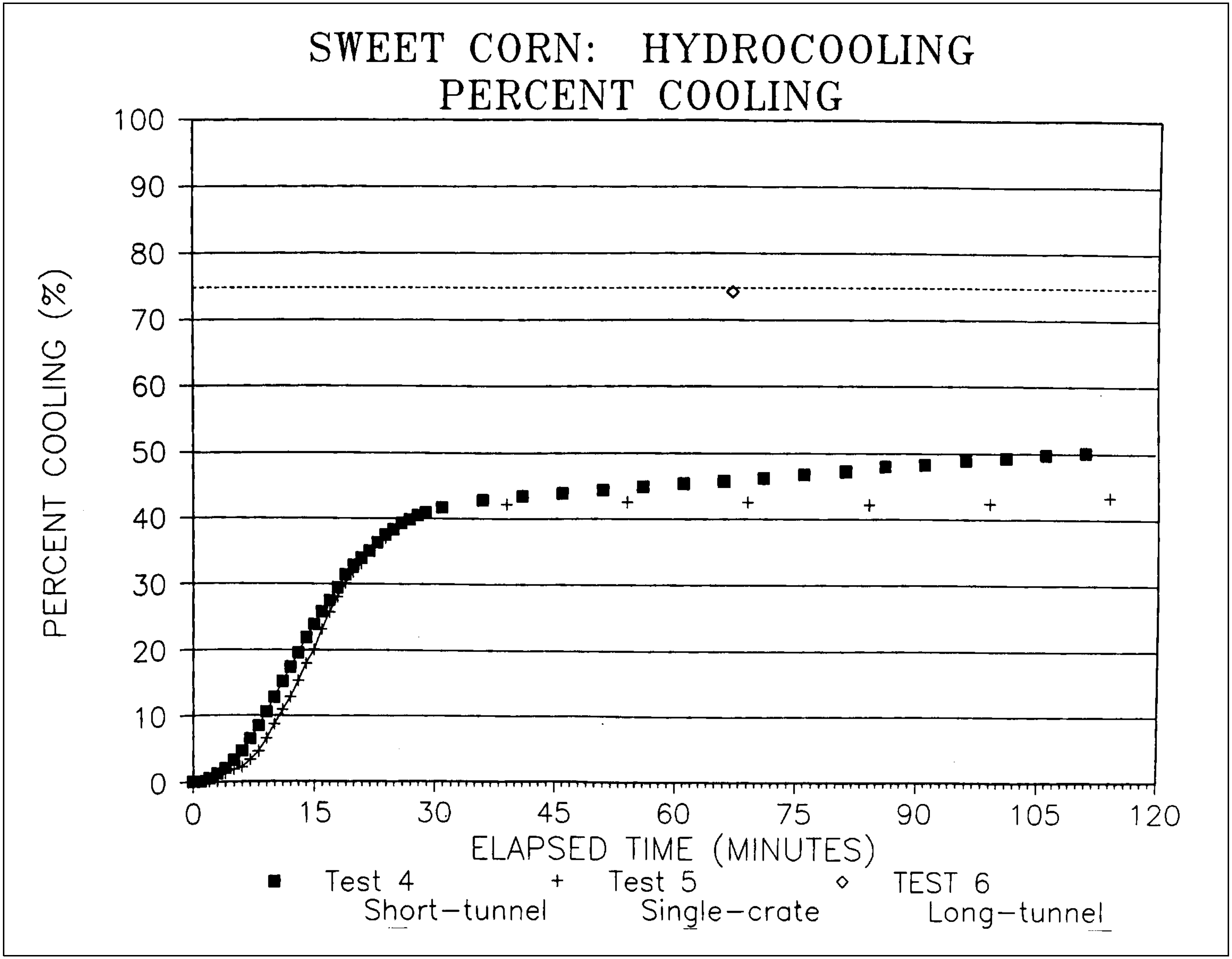

Figure 6B. Percent of initial temperature cooling curves for hydrocooling precooling (Tests 4, 5, and 6).

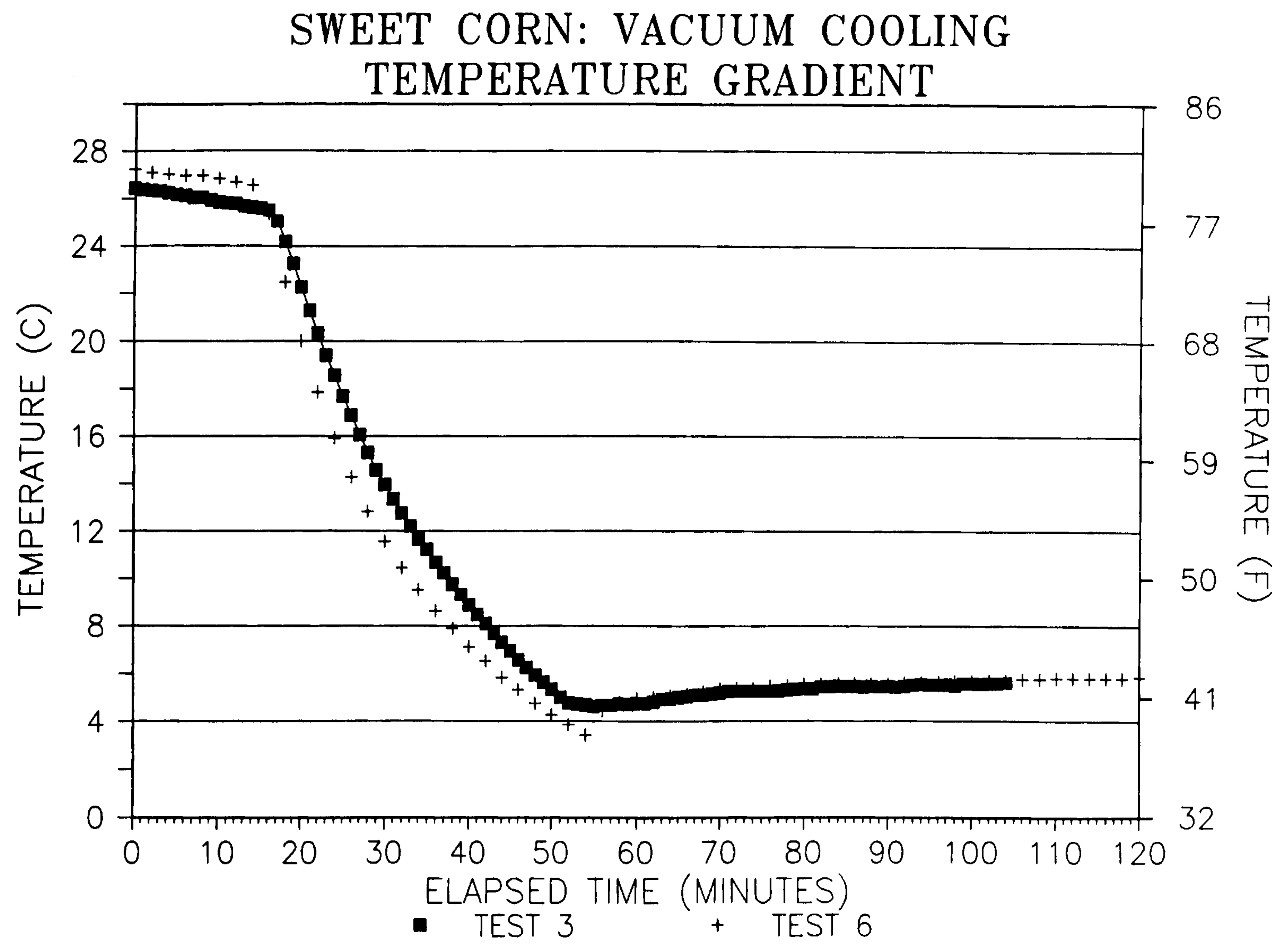

Figure 7A. Time-temperature relationships for sweet corn precooled using vacuum cooling (Tests 3 and 6).

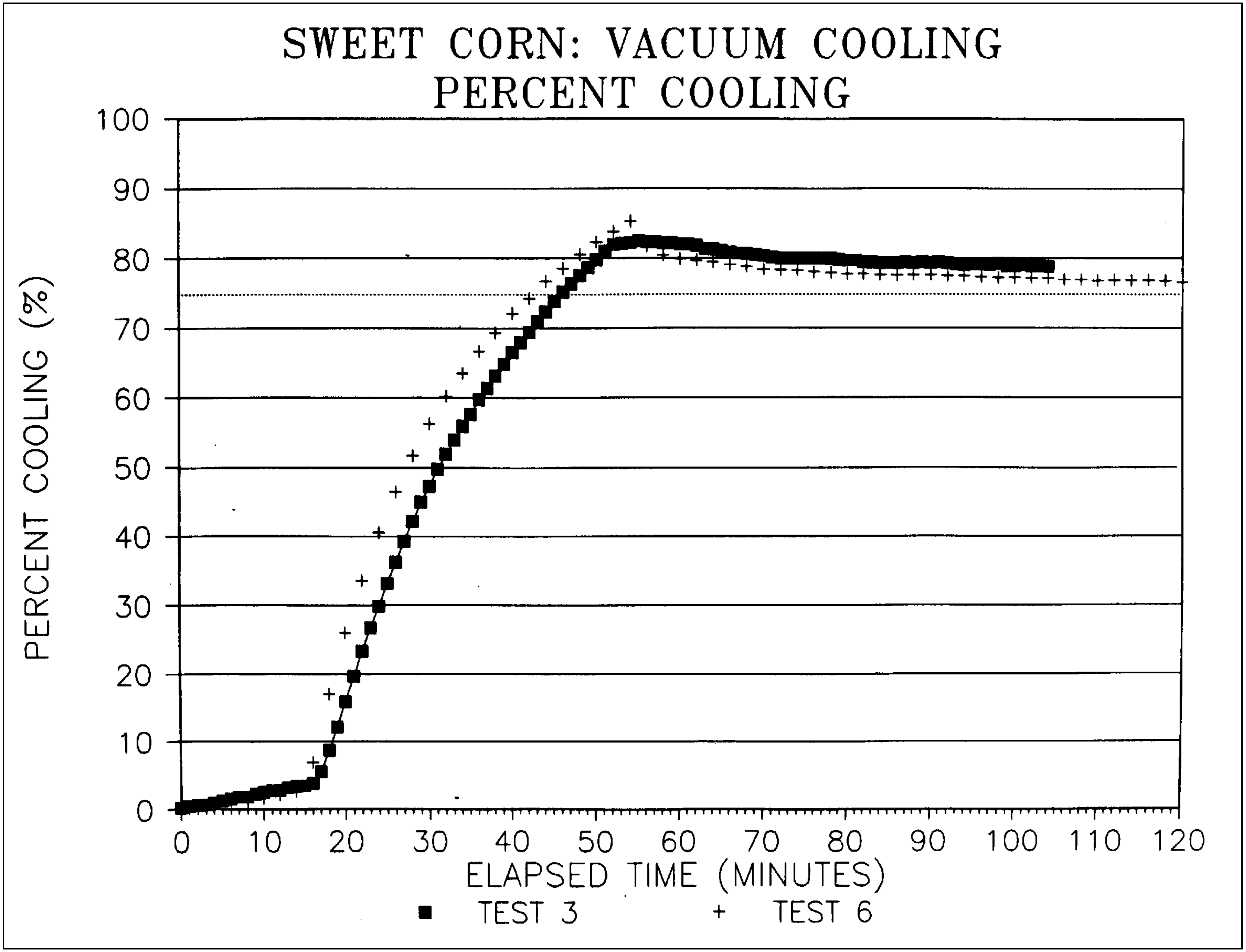

Figure 7B. Percent of initial temperature cooling curves for vacuum precooling (Tests 3 and 6).

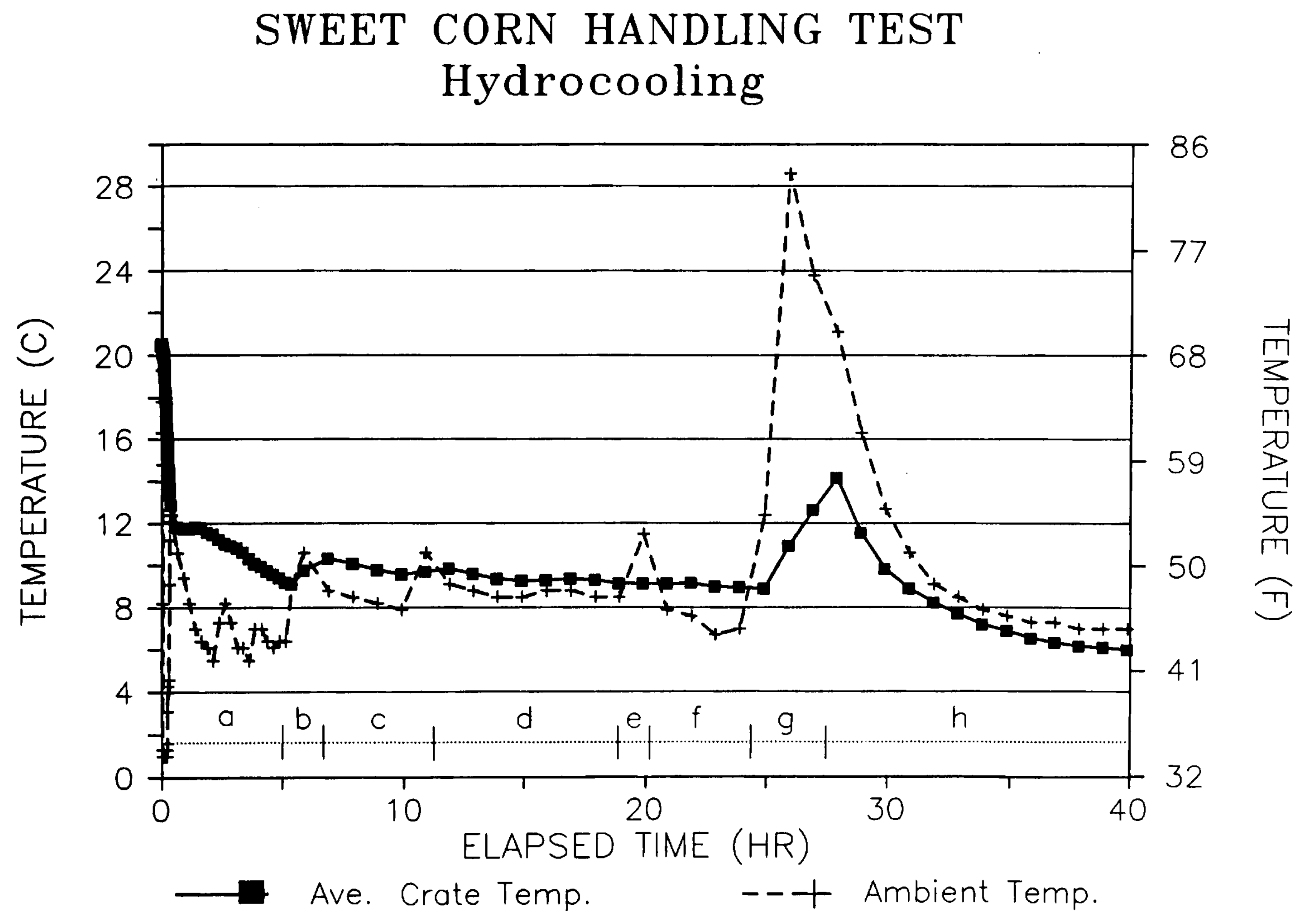

Figure 8. Time-temperature relationships for sweet corn precooling using hydrocooling during commercial shipment and storage (Test 5). KEY TO HANDLING STEPS: a, precooled, placed in packer's cold room (3-4°C (37-39°F)); b, transported to shipper (ambient); c, held in shipper's cold room (8°C (46°F)); d, loaded refrigerated trailer, transported to receiver (Jacksonville) (5°C (41°F)); e, f, unloaded trailer, placed in receiver's cold room (7°C (45°F)); g, transported to Vegetable Crops Dept. (Gainesville) (ambient); h, placed in postharvest cold room (5°C (41°F)).

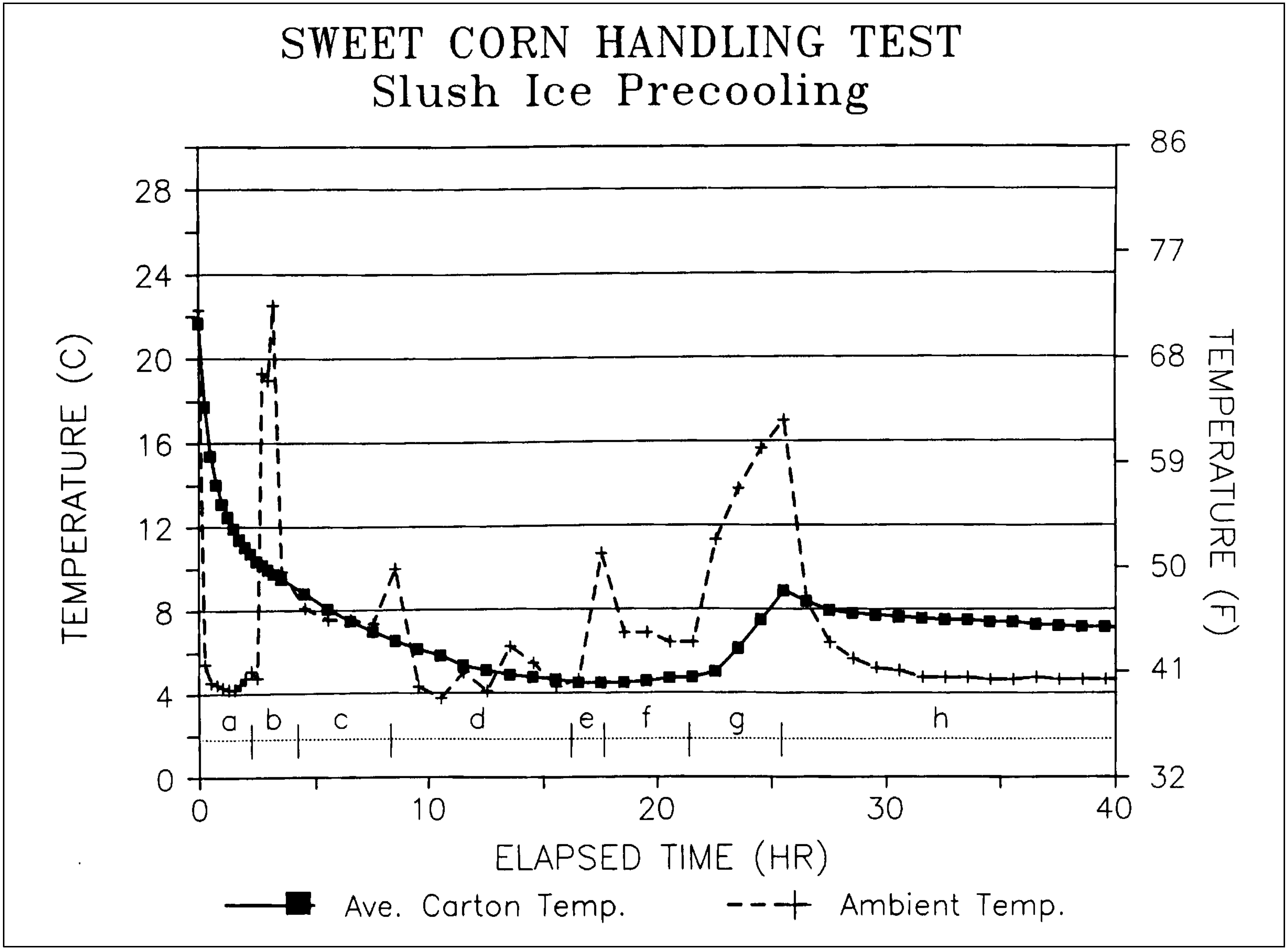

Figure 9. Time-temperature relationships for sweet corn precooling using slush-ice during commercial shipment and storage (Test 5). See Figure 8 for legend to handling steps.

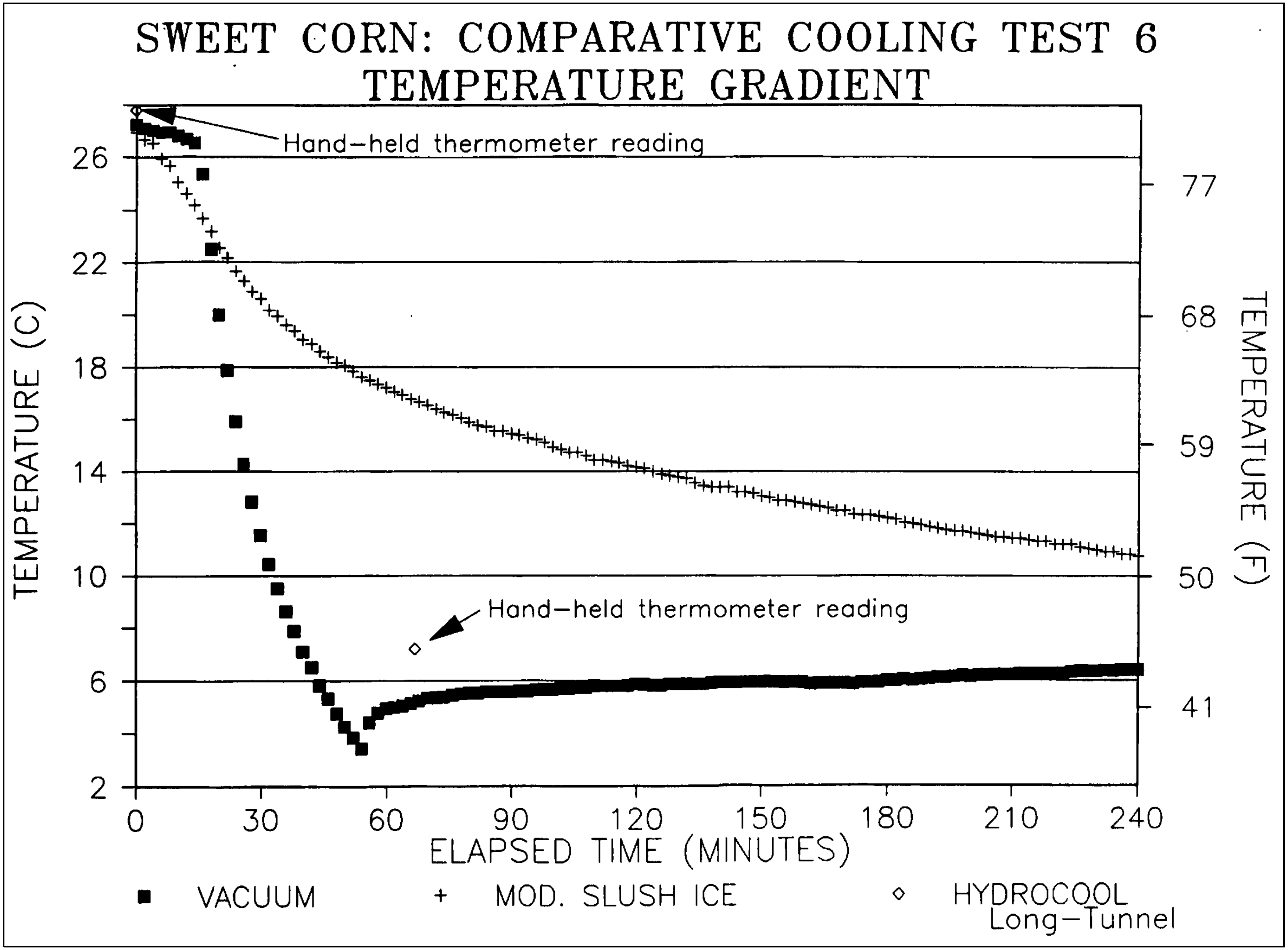

Figure 10A. Comparative time-temperature relationships for sweet corn precooling using modified slush-ice, hydrocooling (partial) and vacuum cooling (Test 6).

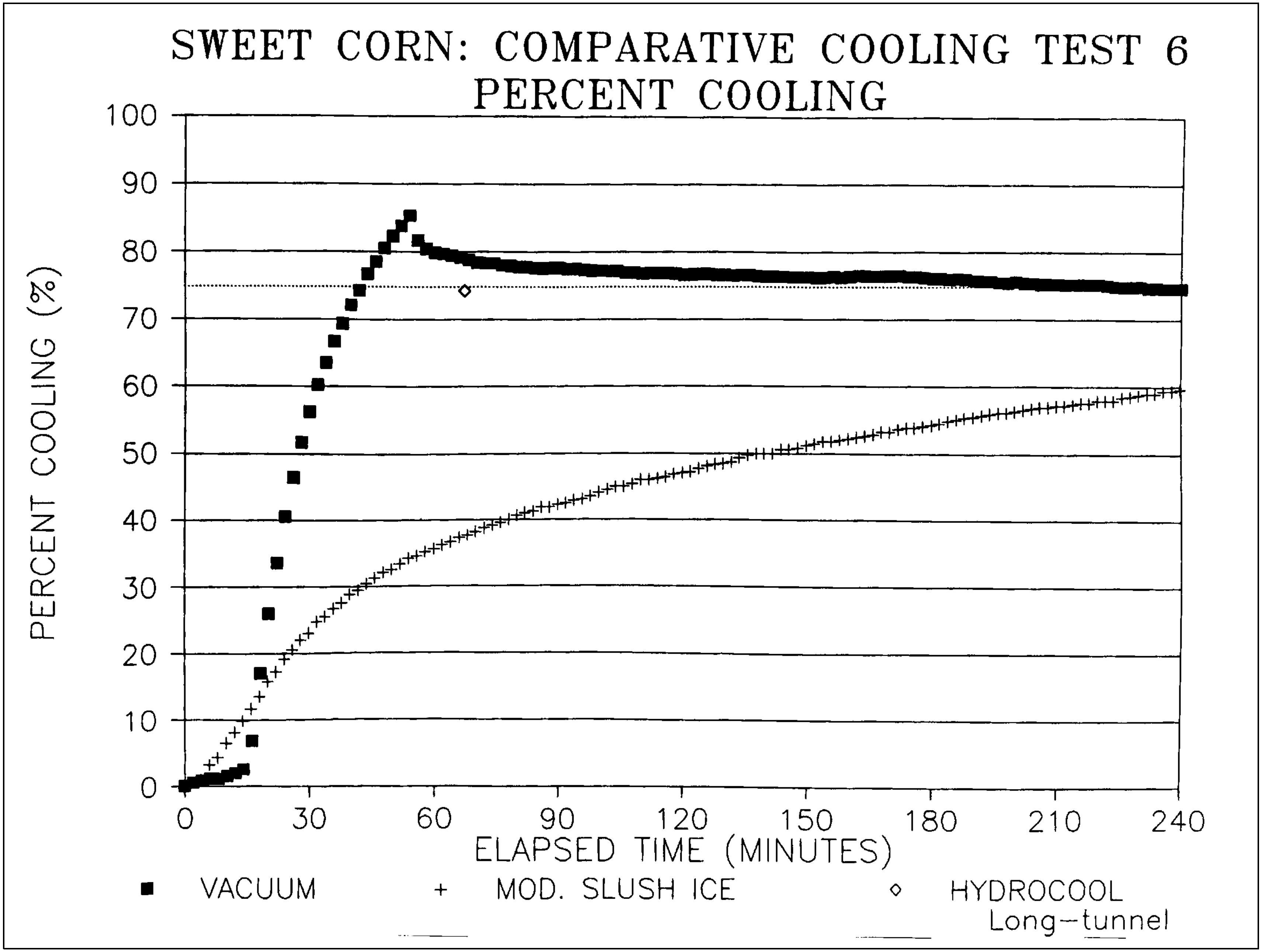

Figure 10B. Comparative percent of initial temperature cooling curves for sweet corn precooling using modified slush-ice, hydrocooling (partial) and vacuum cooling (Test 6).