

COOLING AND SHIPPING STUDIES ON TABLE GRAPES
(Vitis vinifera L.)

BY

MDUDUZI E. K. NGCOBO

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SUPERVISOR

Dr M. Huysamer – Department of Horticultural Science, University of Stellenbosch.

CO-SUPERVISOR

Prof. G Jacobs - Department of Horticultural Science, University of Stellenbosch.

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:

Date:.....

SUMMARY

Fruit quality is the most important factor that determines prices for the fruit in the international markets. Although different consumers perceive quality differently there are quality variables that are always associated with poor quality by all consumers. In table grapes (*Vitis vinifera L.*) these variables may include overall appearance, stem condition, SO₂ damage, decay, berry browning and shatter. The presence of these quality defects negatively affects prices and most often results in quality claims.

Cooling is the most widely used method to reduce the postharvest loss of fruit quality. In South Africa, most deciduous fruits including table grapes are forced air cooled to a statutory pulp temperature of -0.5°C prior to shipping in an effort to preserve quality, thus ensuring good market prices for the fruits. Despite these efforts, there are still quality claims from the markets and this reduces the returns to the growers.

The objectives of this research were to: (i) see if cooling time can be reduced by cooling to higher pulp temperatures of 1.5°C and 3°C without causing quality losses, thus improving the throughput of the cold rooms; (ii) see if the problem of berry browning can be alleviated by cooling grapes to higher pulp temperature, and (iii) see whether pallet positioning in the cooling tunnels and reefer container affect quality.

The trends showed better quality when 'Victoria' and 'Regal Seedless' were forced air cooled (FAC) to pulp temperatures of 1.5°C and 3°C as opposed to -0.5°C . There were no economic losses associated with pre-cooling grapes to pulp temperatures of 1.5°C and 3°C . There were no significant differences in berry browning related to pre-cooling treatments. However, cooling time was reduced significantly. In most of the cooling tunnels and reefer containers used in this trial, grape quality results showed no significant differences between the positions in the stack and in reefer containers. However, in cases where there were significant differences, the middle and the rear positions showed better grape quality in terms of stem condition (dry and brown stems) than the front position (near fan) in both the pre-cooling stack and reefer containers.

The trends showed that the front is cooler than the back of the pre-cooling stack. The pulp temperature differences between the front and rear positions in the reefer container were as high as 1.23 °C. The trends also showed that the bottom layers of the pallets were cooler than the top layers in the reefer container.

FAC to 3°C resulted in a constant reduction in percentage electrolyte leakage after 4 weeks of storage at -0.5°C, while FAC to 1.5°C, -0.5°C and static room cooling (control) in some cases showed an initially low electrolyte leakage followed by an increase in leakage after 4 weeks of storage.

FAC grapes to higher pulp temperatures of 3°C and 1.5°C could reduce the cooling time, thereby improving the throughput of cold rooms. There was no clear evidence to suggest that browning was due to pre-cooling practices. Both preharvest and postharvest conditions need to be further investigated to better understand the problems of browning in white table grapes.

OPSOMMING

Vrugkwaliteit is 'n kritiese faktor in die bepaling van pryse op die internasionale markte. Alhoewel daar variasie voorkom tussen verbruikers in wat vrugkwaliteit is, bly sekere aspekte altyd onveranderd. Ononderhandelbare kwaliteit aspekte in tafeldruiwe (*Vitis vinifera* L.) sluit die algemene voorkoms, toestand van die trosstingels, SO₂ skade, bederf, korrel verbruining en los-korrels in. Indien enige van die kwaliteit-defekte voorkom het dit 'n negatiewe impak op die prys en lei gewoonlik tot gehalte eise.

Verkoeling word algemeen gebruik om die verlies van na-oes kwaliteit te verminder. Die meeste sagtevrugte geproduseer in Suid Afrika (insluitend tafeldruiwe) ondergaan geforseerde verkoeling tot 'n statutêre pulptemperatuur van -0.5°C, voor verskeping. Ondanks hierdie maatreëls om hoë pryse te verseker, is daar steeds kwaliteiteise in die mark wat lei tot 'n laer inkomste vir produsente.

Die navorsing het dus ten doel gehad om : (i) te bepaal of die tyd van verkoeling verminder kan word, indien na hoër pulptemperature van 1.5°C en 3°C verkoel kan word, sonder 'n verlies in kwaliteit en sodoende die deurvloeitempo van die koelkamers verhoog; (ii) om te bepaal of die voorkoms van korrelverbruining verlaag kan word indien tot hoër pulp-temperature verkoel word, en (iii) laastens om te bepaal of posisie van die palet in die verkoelingsstonnel en verskepingshouer 'n invloed het op vrugkwaliteit.

Tendense toon dat 'Victoria' en 'Regal Seedless' kwaliteit beter was indien verkoel tot pulptemperature van 1.5°C en 3°C in vergelyking met -0.5°C. Daar was geen ekonomiese verliese waargeneem indien die hoër verkoelings-temperature gebruik is nie. Alhoewel daar geen betekenisvolle verskille in korrelverbruining voorgekom het tussen temperatuur behandelings nie is die verkoelingsperiode verkort. In die meeste van die verskepingshouers, asook in posisies tydens geforseerde verkoeling is daar geen betekenisvolle verskille waargeneem nie. In die gevalle waar daar egter wel

betekenisvolle verskille voorgekom het, het die middel en agter posisies beter vrugkwaliteit gehad as die voorste posisie tydens verkoeling asook houerverskeping.

Die palette aan die voorkant (naby die waaier) het as 'n algemene tendens laer temperature as in die agterkant van die verkoelingstonnel. Verskille in pulptemperature tussen palette in die voor en agterkant van verskepingshouers was so hoog as 1.23°C. Die temperatuurdata het uitgewys dat die onderste laag kartonne neig om by 'n laer temperatuur te wees as die boonste lae kartonne tydens houerverskeping.

Geforseerde verkoeling teen 3°C het gelei tot 'n afname in persentasie elektrolietlekkasie na 4 weke van verkoeling teen -0.5°C. Terselfdertyd het geforseerde verkoeling tot 1.5°C en -0.5°C asook statiese verkoeling (kontrole) in sekere gevalle gelei tot 'n laer aanvanklike uitlek van elektrolietlekkasie, gevolg deur 'n verhoging na 4 weke opberging.

Geforseerde verkoeling van tafeldruive tot pulptemperature van 1.5°C en 3°C verkort die verkoelingstyd en verhoog dus die deurvloeiempo in die verkoelingskamers. Daar was gedurende die studie geen duidelike bewyse gevind dat korrelverbruining voorkom as gevolg van verkoelingspraktyke nie. Beide voor en na-oes praktyke sal verder ondersoek moet word om die invloed daarvan te bepaal op die verbruining van wit tafeldruive.

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**DEDICATED TO MY PARENTS, SIPHO AND FLORENCE NGCOBO AND MY
BROTHER SIBONAKALISO**

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1. LITERATURE REVIEW: THE IMPORTANCE OF COOLING AND PROPER COLD CHAIN MANAGEMENT ON MARKET QUALITY OF FRUITS

1.1 INTRODUCTION

Cooling is the most active method to control postharvest ripening and senescence of vegetables and fruits in practice (Arin *et al.*, 2004). After harvest, many horticultural products are susceptible to deterioration. Table grapes, for example, should be cooled promptly and thoroughly after harvest in order to maintain their quality (Nelson, 1978). The reasons why table grapes (and probably most other horticultural products) should be cooled thoroughly are: to minimize water loss from the fruit, to retard development of decay caused by fungi, and to reduce the rate of respiration (Nelson, 1978).

Biochemical reactions are retarded by low temperatures (Arin *et al.*, 2004), therefore reducing fruit temperature reduces deterioration of fruit and retains its saleable quality. Most decay organisms do not grow at low temperatures with the exception of a few organisms. Prompt, thorough cooling is thus essential to minimise the problems of fruit rotting during transport and distribution (Mitchell, 1987).

The loss of attractiveness of cut flowers has been related to many factors and the level of ethylene production is one of the most significant (Brosnan *et al.*, 2001). The reduction in temperature has the added advantage of reducing the production and sensitivity of the produce to ethylene that accelerates ripening and senescence (Brosnan *et al.*, 2001).

It can therefore be stated that cooling is important in ensuring the freshness and quality of the fruit delivered to the distant markets, as it retards a number of deteriorative processes.

1.2 IMPORTANCE OF PRE-COOLING ON FRUIT QUALITY

Pre-cooling, as reviewed by Brosnan *et al.* (2001), was first introduced by Powell and his co-workers in the US Department of Agriculture in 1904. It has since been defined in various ways: the removal of field heat from freshly harvested produce in order to slow down metabolism and reduce deterioration prior to transport or storage; immediate lowering of commodity field heat following harvest; and the quick reduction in temperature of the product (Brosnan *et al.*, 2001). It has been pointed out that pre-cooling is likely the most important of all the operations used in the maintenance of desirable, fresh and saleable produce (Brosnan *et al.*, 2001).

1.2.1 The influence of lag time prior to cooling

One important factor which is often under emphasized when considering the cooling of horticultural products is the lag time between harvesting and the commencement of pre-cooling. Nunes *et al.* (1995), did some work on the effect of delaying pre-cooling of strawberries after harvest. Their results showed that delaying pre-cooling increased the loss of water from the fruit, lower tissue firmness, and increased losses of ascorbic acid, soluble solids, fructose, glucose and sucrose compared to the controls. Based on these results, the importance of minimizing the time between harvest and the commencement of pre-cooling cannot be over-emphasized.

1.2.2 The influence of pre-cooling on water loss

Wilting and shriveling seriously damage the appearance of produce and reduce a product's consumer appeal and market value (Thompson *et al.*, 1998). Some perishables, particularly leafy vegetables, appear shriveled or wilted after water loss of only a small percentage of their weight at harvest (Table 1) (Thompson *et al.*, 1998). There are at least three symptoms of water loss from grapes (Nelson, 1979). First to appear are shriveled stems that usually become brittle and break easily when handled (Nelson, 1979). The rate

of stem drying is not only related directly to temperature, but the rate increases logarithmically. For example, the increase in the rate of drying is much greater from 27 °C to 32 °C than from 21 °C to 27 °C, and greatest from 32 °C to 38 °C. The second symptom of water loss to appear is browning of the stems. Such stems detract seriously from the appearance of the grapes. The rate of stem browning increases more rapidly with temperature than does the rate of stem drying. The third symptom of water loss is shrinkage of the berries. Grape berries do not show symptoms of water loss until shrinkage is quite evident on the stems. However, at about 3 percent loss in weight, the berries start to appear dull as the taut condition of the skin slackens. At 4 to 5 percent loss the berries feel definitely soft, and above a 5 percent loss fine wrinkles start to appear radiating out from the pedicel. As in the case of the stems, the rate of berry softening is related directly to temperature before cooling. Grapes held 8 hours at 38 °C had 75 percent of the berries rated “soft”, whereas the lot held at 21 °C had only 45 percent soft berries (Nelson, 1979).

Water is lost from produce in the form of water vapour (Thompson *et al.*, 1998). Fruits and vegetables are composed of cells loosely bound together, with a considerable amount of interconnecting intercellular spaces that lead to natural openings and wounds. Water from the cells vaporizes into the intercellular space and maintains a nearly saturated atmosphere within the product. Water vapour moves to the outside atmosphere through lenticels, stomates, stem scars, injured areas, or directly through the cuticle (Thompson *et al.*, 1998).

Table 1. Water loss at which commodities become unsalable, in order of increasing maximum weight loss.

Commodity	Maximum weight loss (% fresh weight)	Reason for loss
Spinach	3	wilting
Broccoli	4	taste, wilting
Turnip with leaves	4	wilting
Tomato	4	shrivel
Leaf lettuce	3-5	wilting, decay
Grape	5	berry shrivel
Pear	6	shrivel
Cabbage	6	shrivel
Apple	7	shrivel
Watercress	7	wilting
Persimmon	7	shrivel
Carrot	8	wilting
Brussel sprouts	8	wilting, rot, yellowing
Green pepper	8	shrivel
Peach	11	shrivel
Winter squash	15	hollow neck

Source: Thompson *et al.* (1998).

Water loss is strictly a physical factor related to the evaporative potential of the surrounding air (Nelson, 1978). It may be expressed directly as the vapour pressure deficit (Vpd), a term which indicates the combined influence of the temperature and relative humidity, and is the factor related directly to the rate of water loss from the fruit (Nelson, 1978). VPD is the vapour pressure in the interior of a commodity minus the vapour pressure of the air surrounding the commodity (Thompson *et al.*, 1998). The air inside the commodity is usually assumed to be saturated or have a 100 percent relative

humidity (RH). High VPD causes rapid water loss (Thompson *et al.*, 1998). The equation may be expressed as follows:

$$V_{pd} = V_p \times \frac{100 - RH}{100}$$

where V_{pd} = vapour pressure deficit (mm of Hg); V_p = vapour pressure (mm of Hg) and RH = relative humidity (%).

It is apparent from the above equation that the V_{pd} increases as the V_p increases (which would occur with a rise of temperature) (Nelson, 1978). Furthermore, the V_{pd} will increase as the RH is lowered. It is to be expected then that the V_{pd} would be especially high during the typically hot, dry conditions that prevail during harvest of table grapes.

1.2.3 Influence of pre-cooling on the respiration rate

Respiration can be described as the oxidative breakdown of the more complex materials normally present in cells, such as sugars and organic acids, into simpler molecules, such as carbon dioxide and water, with the concurrent production of energy and other molecules which can be used by the cell for synthetic reaction and maintenance of the harvested product (Wills *et al.*, 1989). This oxidative breakdown of complex material into simpler molecules results in the loss of fruit quality and subsequently leads to fruit senescence.

The respiration process can be written empirically as: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673 \text{ kcal}$ (Hardenburg *et al.*, 1986). It is apparent from the respiration formula that during this process, energy is released (kcal). This released energy is in the form of ATP (roughly 70 %) and heat and the amount of heat released varies with the commodity and increases as temperature increases, up to about 38 to 40 °C. This heat is called vital heat and is always part of the refrigeration load that must be considered in handling fruits, vegetables, and cut flowers in cold storage rooms. Heat evolution is expressed in joules in the metric system. For each milligram of CO_2 produced by respiration, 2.55 cal of heat

are generated, so the value of 2.55 is used in computing the heat evolution (Hardenburg *et al.*, 1986). One calorie is the amount of heat required to raise the temperature of 1 g of water by 1°C. One calorie equals 4.187 J, so heat evolution in the metric system is computed by multiplying each milligram of CO₂ by a factor of 10.676. The value of 10.676 is calculated by multiplying 2.55 cal/mg CO₂ by 4.187 J/cal (Hardenburg *et al.*, 1986). Effective pre-cooling is therefore required to remove the respiratory heat from the produce and thus reduce the heat load.

Temperature has a pronounced effect on the respiratory rate of harvested products. As product temperature increases, biological reaction (respiration) rates increase logarithmically (Fig.1) (Kays *et al.*, 2004). For every 10 °C rise in temperature, the rate of respiration is roughly doubled or tripled (Hardenburg *et al.*, 1986).

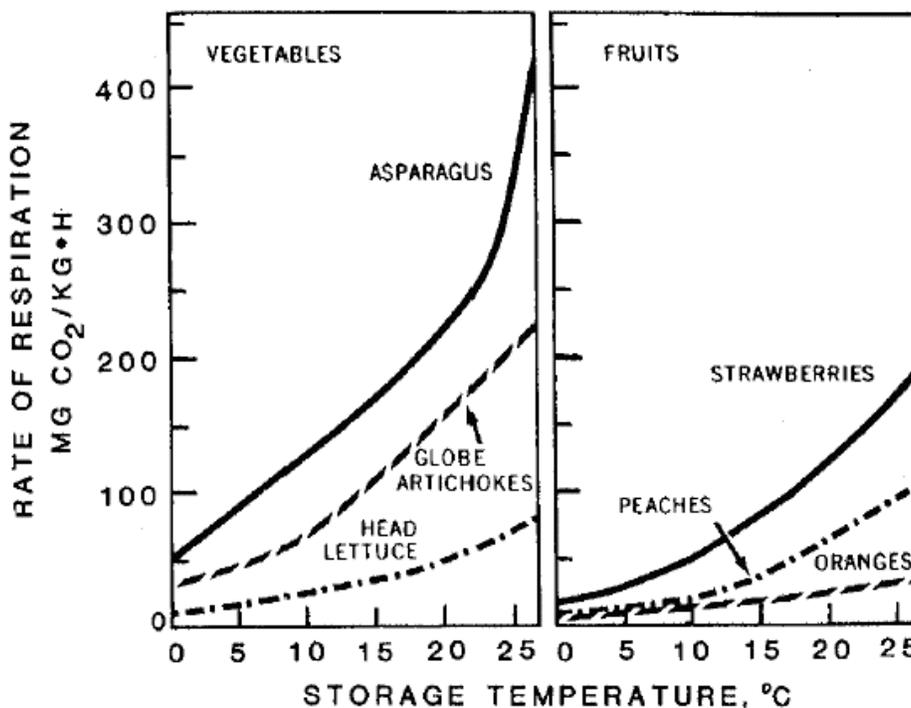


Figure 1: Respiration rates of three fruits and vegetables stored at different temperatures (Hardenburg *et al.*, 1986).

The change in rate with temperature follows van't Hoff's rule fairly closely, which states that the rate of most chemical and biochemical reactions increases two to three times with every 10 degrees rise in temperature. For example, an apple held at 10 °C ripens and respire about three times as fast as one held at 0 °C, and one held at 20 °C respire about three times as fast as at 10° (Hardenburg *et al.*, 1986). Similarly, a head of lettuce respire about three times faster at 10 °C as at 0 °C and two or three times as fast at 20 °C as at 10 °C (Hardenburg *et al.*, 1986). Some products have high respiration rates and hence, require considerably more refrigeration than more slowly respiring products to keep them at a specified temperature. Looking at figure 1 for example, asparagus respire approximately 10 times as fast as lettuce. Since respiration is strongly influenced by the product temperature, pre-cooling and refrigeration is of prime importance in retarding respiration and ensuring good fruit quality.

The double response of metabolic processes to every 10 °C rise in temperature is called the temperature quotient (Q10), which can be predicted by Van't Hoff's rule as follows:

$$Q_{10} = [J_2/J_1]^{10/t_2-t_1}$$

Where J1 and J2 are the respirations at temperatures t1 and t2, respectively.

Using this equation, the product shelf life can be predicted as shelf life is generally regarded as the inverse of the rate of deterioration. Pre-cooling is thus essential in order to reduce metabolic changes catalysed by enzyme activity, and to slow the senescence of horticultural products (Brosnan *et al.*, 2001).

1.3 METHODS OF PRE-COOLING

There are different methods that can be employed to cool down the produce. These include room cooling, forced-air cooling, hydro-cooling, evaporative cooling and vacuum cooling (Wills *et al.*, 1989). These methods use different modes and media for their function. Room cooling and forced-air cooling use cold air, hydro-cooling makes use of cold water, direct contact with ice, and evaporative cooling and vacuum cooling employs

the evaporation of water. Fruits are normally cooled with cold air, although stone fruits benefit from hydrocooling, while vegetables may be cooled by employing any of the above-mentioned cooling methods, depending on the physiology and market requirements of the individual vegetables (Wills *et al.*, 1989).

1.3.1 Room Cooling

In this cooling technique, produce in boxes, cartons, bulk containers or other packages is exposed to cold air in a normal cool store (Wills *et al.*, 1989). For adequate cooling, air velocities around the packages should be at least 60 meters per minutes. The produce may be cooled and stored in the same place thus requiring less re-handling, and peak loads on the refrigeration system are less than those of the faster cooling systems. The main disadvantage of this technique is the fact that the rate of cooling is relatively slow and thus may be inadequate for more sensitive produce (Wills *et al.*, 1989), such as table grapes and cut flowers.

1.3.2 Forced Air Cooling

In this technique the rate of cooling with cold air is increased significantly. This is achieved by enlarging the heat transfer surface from that of the package to the total surface area of the produce (Wills *et al.*, 1989). The technique employs forcing the air through the packages and around each piece of produce. Forced-air cooling can cool produce in about one-quarter to one-tenth the time required for room cooling. Room cooling removes heat from only the surface of the package, the size and shape of the package being the limiting factor (Wills *et al.*, 1989). By setting up a pressure gradient across the package, there is a positive flow of cooling air through the container from one side to the other providing direct contact with the packed fruit (Nelson, 1979). The pressure differential between opposite faces ranges from barely measurable to about 250 Pascals (25 mm water gauge), and airflows vary between 0.1 and 2 L.sec⁻¹.kg⁻¹ (Wills *et al.*, 1989). The speed of cooling can be adjusted by varying the rate of airflow (Wills *et al.*, 1989).

1.3.3 Hydro-cooling

In hydrocooling, water acts as the heat transfer medium (Wills *et al.*, 1989). This method is rapid for cooling produce, since water has a far greater heat capacity and heat conductance than air. Hydrocooling is rapid if water contacts most of the surface of the produce and is maintained as close to 0°C as possible (Wills *et al.*, 1989). In many hydrocooling systems, the produce is passed under cold showers on a moving conveyor (Wills *et al.*, 1989). The main downfall of this system is the fact that it requires that the produce be packed in water resistant packaging material, which most packaging materials being used in the fruit industry are not. Another limiting factor is that wetting the fruit e.g. table grapes is undesirable as it aids germination of fungal spores (Ginsburg *et al.*, 1978). For these reasons, forced-air cooling is still the best technique of pre-cooling the produce.

1.4 EFFECTIVE TEMPERATURE MANAGEMENT DURING COLD STORAGE

In the majority of food refrigeration systems, heat is transferred primarily by convection: therefore, the temperature and its homogeneity are directly governed by the patterns of airflow (Smale *et al.*, 2006). Spatial variation in produce temperature in a good cold store should not exceed 1°C above or below the nominal storage temperature (Wills *et al.*, 1989). The single most important requirement for uniform produce temperatures is uniform cooling over the entire area on the top of the stack (Wills *et al.*, 1989). As reviewed by Smale *et al.* (2006), recent studies have shown a significant level of spatial temperature variability in some food refrigeration systems, with non uniform airflow implicated as a major cause of this variability. Ideally there should be a continuous, narrow, air slot in the direction of airflow past at least two faces of every box or carton and each side of every bulk bin, together with no large vertical gaps in the stack to allow short-circuiting by the cool air (Wills *et al.*, 1989). The cold room should be well

insulated to reduce heat leakage, and the coolers should have ample capacity to ensure a small difference between the temperature of the air and coil surface.

Air movement transfers heat from the fruit to the coils, by forced circulation in rooms cooled by forced draft coolers. The nature of packages and method of stacking must allow the air to move readily through all parts of the stack for produce to be cooled quickly and uniformly (Wills *et al.*, 1989).

Warm produce should preferably be cooled in a separate cool room from that used for storage. If only one room is available, the designed daily intake (commonly 10 percent of available cooling capacity) should not be exceeded, otherwise, the life of the produce will be reduced and shrinkage promoted (Wills *et al.*, 1989). Warm produce should be loose stacked, and cooling can be improved with the aid of an auxiliary portable fan placed in front of the stack, with the suction side to the produce, to draw air through it (Wills *et al.*, 1989).

1.4.1 Cooling Rates and Refrigeration Capacity

The rate of cooling of produce is dependent primarily upon:

- Rate of heat transfer from the produce to the cooling medium, which is especially influenced by rate of flow of the cooling medium around or into the containers of produce;
- Difference in temperature between the produce and the cooling medium;
- The nature of the cooling medium; and
- The thermal conductivity of the produce (Wills *et al.*, 1989).

When hot produce is exposed to cool air, kept at a constant temperature by refrigeration, the rate of cooling ($^{\circ}\text{C}$ per minute) is not constant, but diminishes exponentially as the temperature differences (driving force) between produce and air falls (Wills *et al.*, 1989). This process is often approximated with the concept of half cooling time, the time required for the product temperature to drop half the difference between the initial

product temperature and the temperature of the cold air (Thompson *et al.*, 1998). In Figure 2, the product is cooled by 24 °F from 80 °F to 56 °F, in the first half cooling period. During the next half cooling period, equal in time to the first, the product also loses half the difference between the product temperatures at the beginning of the period (56 °F) minus the temperature of the cold air (32 °F). But, because the temperature difference at the beginning of the second period is half of the temperature difference at the beginning of the first half cooling period, the temperature drop during the second half cooling period is half as much, only 12 °F (Thompson *et al.*, 1998). Most products are left on the cooler for three half cooling periods, seven-eighths cool, or four half cooling periods, fifteen-sixteenths cool (Thompson *et al.*, 1998). This cooling pattern demonstrates the need to keep cold air close to its set point temperature, especially near the end of cooling. If the refrigerated air temperature rises only a few degrees in the third or fourth half cooling periods, products may nearly stop cooling. Tunnel coolers should be built as individual rooms or divided into sections so that warm products arriving later in the day will not affect the air temperature near batches that are almost cooled (Thompson *et al.*, 1998).

Because the rate of cooling varies, alternative ways of describing the cooling process are used and two parameters are:

1. The cooling coefficient defined as the ratio of the change in temperature per unit time at any moment to the difference in temperature between produce and air at the same moment;
2. The time required to reduce the temperature difference between produce and cooling medium by one half (Z) or by seven-eighths (S) (Wills *et al.*, 1989).

Theoretically, Z and S are independent of the initial produce temperature and remain constant throughout the cooling period (Wills *et al.*, 1989). S is more useful in commercial cooling operations because the temperature of the produce at seven-eighths cooling time is close to the required storage or transport temperature (Wills *et al.*, 1989) (Figure 2). In systems where the cooling rate is rapid the temperature change in the interior of produce lags considerably behind the change in surface temperature. This lag

affects the relation between S and Z such that S may range from 2Z to 3Z. Mathematically, seven-eighths cooling is expressed as:

$$S = \ln(8j)/C,$$

Where j is the lag factor, which may vary from 1 to 2 at the center of cooling objects, and C is the cooling coefficient, a negative value (Wills *et al.*, 1989). The rate of cooling of produce will be influenced by the cooling method, type of package, and the way the packages are stacked (Wills *et al.*, 1989).

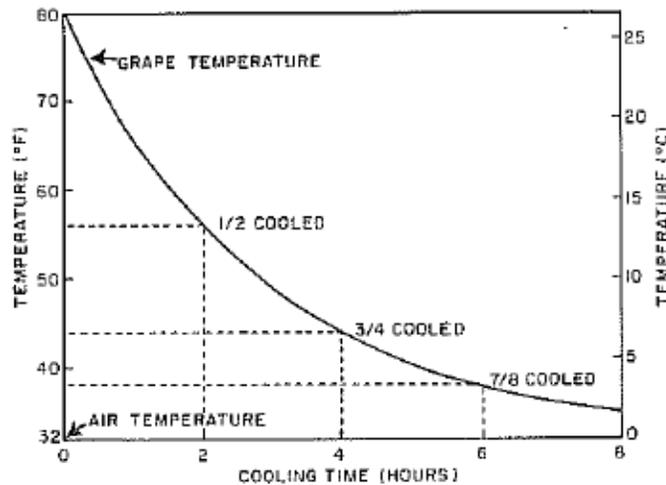


Figure 2: Illustration of the principle of half-cooling time (Nelson, 1979).

A common cause of slow cooling is inadequate refrigeration capacity (Nelson, 1979). Typically, a fruit cooling facility will normally have high demands placed on its capacity during the afternoon and early evening hours as increasing volumes of warm fruit are placed on line for cooling. Figure 3 shows what can happen to cooling rates of table grapes in a facility with inadequate (as contrasted with adequate) refrigeration capacity during a typical 24-hour cycle. Assumed is an initial fruit temperature of 27°C, a half-cooling time for the facility of 3 hours (if not overloaded) and a refrigeration capacity adequate to keep the cooling air at 0°C throughout the cycle (again, if not overloaded). Grapes placed in the cooler at noon can be expected to reach 4°C before 9 p.m. However, fruit placed in the facility, if it had the inadequate temperatures shown, would not reach

this temperature until after 4 a.m. the next morning, a needless loss in quality caused by more than seven extra hours of cooling and a whole day's delay in shipment to market (Nelson, 1979). The cooling rates shown in Figure 3 are achievable only where very high cooling capacities, high airflows and well-ventilated packages are used.

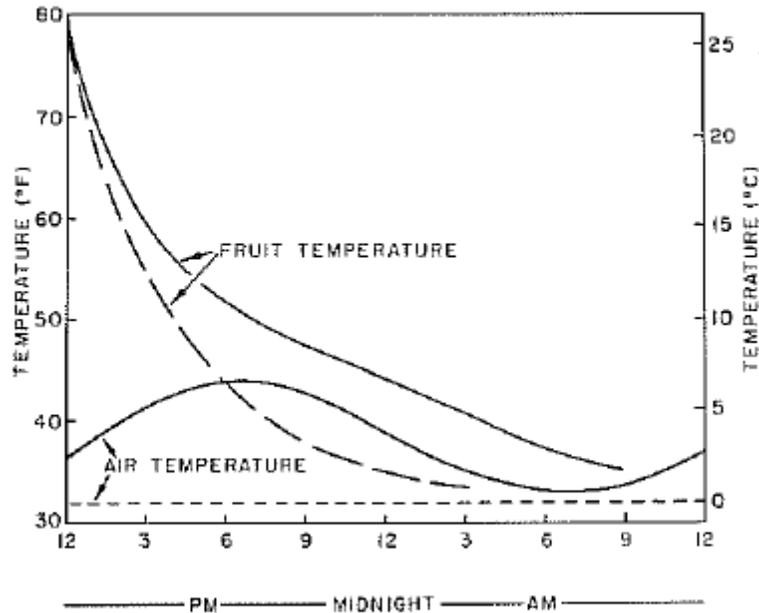


Figure 3: Effect of overloading a cooler with hot grapes on the cooling rate of the fruit (Nelson, 1979).

1.4.2 The Relative Humidity in Cooling fruits

Maintaining a low temperature is the primary consideration in securing fast cooling of grapes, but maintaining a high relative humidity (RH) during the process is important and often neglected (Nelson, 1979). A low RH can cause considerable loss of water from the fruit during cooling, even though the period may be relatively short (Nelson, 1979). Such water loss frequently happens when the coil temperature is lowered in order to increase the cooling capacity of the unit (Nelson, 1979). When this is done, the colder coil condenses more moisture from the air, lowering its RH. Further, the source of this moisture is largely from the fruit itself (Nelson, 1979). If the difference between the return air temperature and the coil temperature is too large, then a heavy condensation

results on the coil. The temperature differential between the cold room air and the coil can be reduced by increasing the coil surface area (Nelson, 1979).

1.5 TRANSPORT COOLING

Refrigerated trucks and containers do not have enough airflow or refrigeration capacity to cool perishable commodities rapidly (Thompson *et al.*, 1998). Produce should always be cooled to their desired transit temperature before loading in highway trailers (Thompson *et al.*, 1998).

Refrigerated marine containers, cargo ships, and rail cars can do some cooling during transport, but cooling is slow (Thompson *et al.*, 1998). Containers and refrigerated ships usually have bottom-delivery airflow and refrigerated air is supplied to the product through a floor plenum. Fastest cooling is obtained when the floor is completely covered with product. Uncovered areas allow poor air distribution in the air plenum and airflow around cartons rather than through them. Cartons must have top and bottom vents to allow vertical airflow through the packages, and vents must align between layers of cartons. Inner packaging materials must also allow vertical airflow (Thompson *et al.*, 1998).

1.6 IMPORTANCE OF MAINTAINING THE COLD CHAIN

Maintenance of the optimum temperature for a given commodity is the predominant factor affecting losses and maintenance of quality (Harvey, 1981). As discussed in the preceding sections, low temperatures retard the processes that deteriorate the fruit quality. Different processes in different fruit kinds characterize deterioration. In grapes for example, deterioration is characterized by weight loss, stem browning, softening, shattering and decay (reviewed by Pretel *et al.*, 2006). Maintaining low temperatures minimizes these defects.

Temperature affects the rate of growth and spread of decay organisms in the same way that it affects the commodity – the lower the temperature, the slower the rate of life processes (Mitchell, 1987). Certain disease organisms will not grow at ideal fruit storage temperatures. An example is the Rhizopus rot (*Rhizopus stolonifer*), which will not grow at temperatures that are less than or equal to 5°C. While many other organisms such as grey mould (*Botrytis cinerea*) and brown rot (*Monilinia fructicola*), which are important decay organisms in fruits such as table grapes and stone fruits, will continue to grow at low storage temperatures (Mitchell, 1987). Low temperatures do not prevent germination but merely delay it (Ginsburg *et al.*, 1978). *Botrytis* spores will germinate when free moisture or very high relative humidity conditions prevail (Ginsburg *et al.*, 1978). When the cold chain is broken, the cold fruits are exposed to higher temperatures, and the water vapour in the warmer air surrounding the fruit tend to condense on the surface of the fruit as the water molecules lose energy. It is thus this condensed water in combination with higher temperatures that provide a conducive environment for the fungal spores to germinate. When a spore germinates, a short infection tube is formed which is capable of penetrating the skin of the fruits even if there are no mechanical injuries or stomata (Ginsburg *et al.*, 1978).

1.7 TEMPERATURE RELATED DISORDERS

1.7.1 Chilling injury

Chilling injury (CI) is a physiological disorder induced by low, non-freezing temperatures that affects both plants and fruit from tropical and subtropical origins (Sanchez-Ballesta *et al.*, 2006). It has been widely reported that the expression of CI symptoms, especially flesh browning or internal browning, develops faster and more intensely when stone fruits are stored at temperatures between 2.2 and 7.7°C (killing temperature zone) than those stored at 0°C or below but above their freezing point (review by Lurie *et al.*, 2005). The symptoms of CI manifest themselves differently in different plant produce. In peaches and nectarines CI symptoms manifest themselves as

dry, mealy, woolly (lack of juice) or hard textured fruit with no juice (leatheriness), flesh or pit cavity browning, and flesh bleeding or internal reddening (Lurie *et al.*, 2005).

The internal browning disorder may be related to tissue deterioration or senescence, which leads to changes in membrane permeability and the interaction between phenols and polyphenol oxidase, which are generally found in separate compartments in the cell (review by Lurie *et al.*, 2005).

1.7.1.1 Symptoms of Chilling injury

Symptoms of chilling injury to horticultural crops are diverse and these include pitting, sheet pitting, shriveling, wilting, scald, surface lesions, water soaking of tissues, internal discolouration (browning), breakdown of tissues, failure of fruits to ripen in the expected pattern, accelerated rate of senescence, increased susceptibility to decay, shortened storage, compositional changes related to consumer acceptance, and loss of normal growth capacity (Murata, 1990; Bramlage *et al.*, 1990). Most of these symptoms are not unique to chilling injury, often making it difficult to diagnose the cause of commercial losses of these crops (Bramlage *et al.*, 1990).

7.1.1.1 Membrane permeability

Membranes are dynamic structures that support numerous biochemical reactions and they are also major targets of environmental stresses (Campos *et al.*, 2003). Chilling impairments mainly consist of alteration of metabolic processes, decrease in enzymatic activities, reduction of photosynthetic capacity and changes in membrane fluidity. Such changes are frequently related to an increase in membrane permeability, affecting membrane integrity and cell compartmentation under stress conditions (Campos *et al.*, 2003). Increased rates of solute and electrolyte leakage occur in a variety of chilled tissue and have been used to evaluate membrane damage following chilling, reviewed by Campos *et al.* (2003). When exposed to chilling, plant cell membranes undergo changes in lipid and fatty acid composition in order to maintain cell functions at low temperatures.

Such changes may result from an increase in the proportion of highly unsaturated fatty acids in phospholipids of most plant cell membranes, such as linoleic acid (C18:3), during low temperature acclimation (reviewed by Campos *et al.*, 2003). More unsaturated (low-melting-point) molecular species of phosphatidylglycerol (PG), determined by higher levels of its major fatty acids, *trans*- Δ^3 -hexadecenoic acid (C16:1*t*), may also contribute to a decrease of phase transition temperature of the total thylakoid lipid, resulting in enhanced membrane stability when temperature decreases (reviewed by Campos *et al.*, 2003).

Lurie *et al.* (1983), found that after removal of apple fruit from storage and simulated shelf life at 20°C for 5 days, the membrane viscosity as well as membrane permeability to electrolytes increased. They also found that the membrane phospholipids showed a decrease in the degree of unsaturation of the fatty acids, and there was an increase in the ratio of sterols to phospholipids. They then suggested that the primary adaptive change during low-temperature storage is an increase in phospholipids content, while during ripening changes occur in the fatty acid composition of the phospholipids and in the sterol: phospholipid ratio.

1.7.1.1.2 Lipid peroxidation

Oxidation of unsaturated fatty acids and their ester possessing the 1,4-*cis*, *cis*-pentadiene system, are catalysed by the enzyme lipoxygenase (LOX) (EC 1.13.1.13), with the primary products being *cis-trans* conjugated hydroperoxides (Ben-Aziz *et al.*, 1970). Lipoxygenase (EC 1.13.11.12) catalyses the oxygenation of long chain fatty acids containing a *cis*, *cis*-1,4-pentadiene structure to hydroperoxides (Skorzynska-Polit and Krupa, 2003).



(Reviewed by Mohammadi *et al.*, 2003).

Linoleic and linolenic acids are the most abundant fatty acids of this structure in plants, and they are ideal substrates for LOX (Skorzynska-Polit and Krupa, 2003). Heme proteins also catalyse peroxidation of unsaturated lipids, a fact that has caused confusion in the past (Ben-Aziz *et al.*, 1970).

It can be seen from the preceding section that the reduction in the unsaturated phospholipid content results in a lack of membrane function under chilling conditions. An increase in saturated phospholipids in the membrane lowers the membrane fluidity and thus increases membrane permeability.

1.7.1.1.3 Fruit Browning (discolouration)

Browning is one of the undesirable reactions that occur in many fruits and vegetables. This browning of fruits, also referred to as fruit discolouration, negatively affects the marketability of many fruits as a result of poor appearance. This physiological disorder occurs internally in some fruits (e.g. plums), externally in other fruits (e.g. litchis) and in some cases both internally and externally (e.g. in some white table grape cultivars). Fruit browning can be divided into enzymatic and non-enzymatic reactions.

1.7.1.1.3.1 Enzymatic browning

Enzymatic browning is catalysed by polyphenol oxidase (Valentines *et al.*, 2005). Polyphenol oxidases or tyrosinases (PPO) are enzymes with a dinuclear copper center, which are able to insert oxygen in a position *ortho*- to an existing hydroxyl group in an aromatic ring, followed by the oxidation of the diphenol to the corresponding quinone (Mayer, 2006). Enzyme nomenclature differentiates between monophenols oxidase (tyrosinate, EC 1.14.18.1) and catechol oxidase or *o*-diphenol:oxygen oxidoreductase (EC 1.10.3.2) (Mayer, 2006). Polyphenol oxidase is responsible for hydroxylation of monophenols to *o*-diphenols and oxidation of *o*-diphenols to *o*-diquinones (Mazzafera *et al.*, 2000). *O*-quinones are then polymerized to brown or dark pigments (melanins) (Valentines *et al.*, 2005). There are many roles that have been proposed that PPO plays in

plants, but much is still unknown about its biological function in plants (Mayer, 2006). At present, the most likely functions for PPO are its involvement in plant resistance against diseases and against insect herbivory (as reviewed by Mazzafera *et al.*, 2000). Enzymatic browning is due to a lack of compartmentation (Fig. 4) within the cell. The lack of the cellular compartmentation results in phenolics being exposed to PPO (Fig. 4). In some fruits this damage is triggered by exposure to chilling temperatures (Jiang *et al.*, 2004).

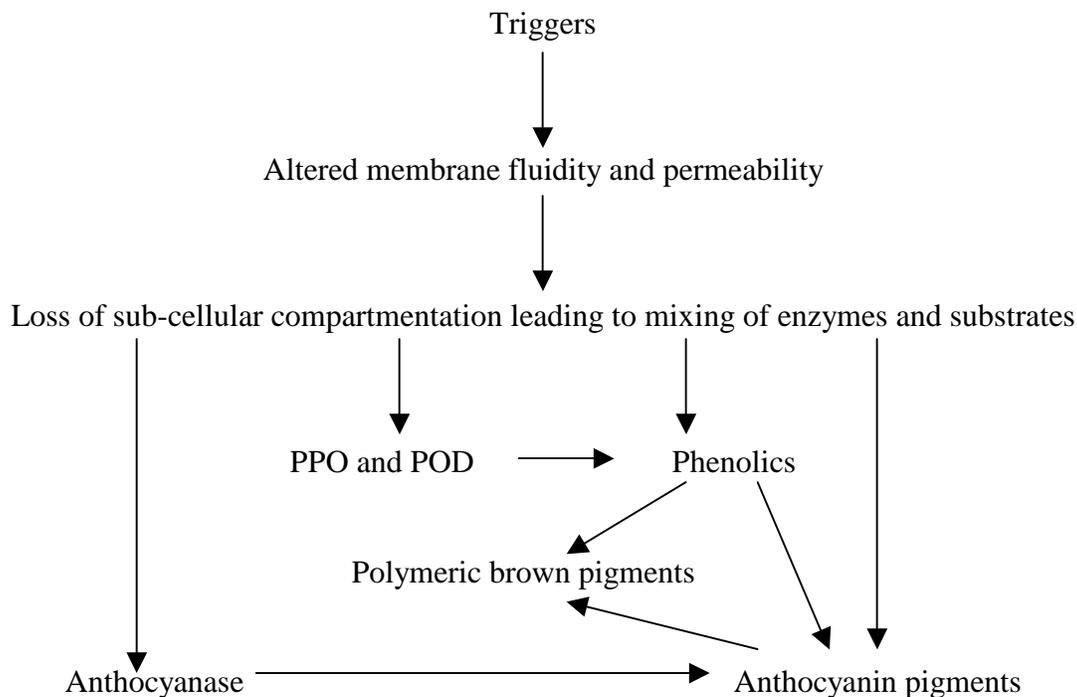


Figure 4: A proposed scheme for enzymatic browning in the pericarp of harvested litchi fruit (Jiang *et al.*, 2004)

1.7.1.1.3.2 Non-enzymatic browning

Non-enzymatic browning is favoured by heat treatments and includes a wide number of reactions such as the Maillard reaction (MR), caramelisation, chemical oxidation of phenols, and maderisation (Manzocco *et al.*, 2001). The Maillard reaction is a complex reaction, since it is influenced by factors such as temperature, pH, time, water activity, type and concentration of buffer, reaction source and sugar involved. Changing any of

these factors will alter reaction rate, reaction pathways and reaction end-products (Sumaya-Martinez *et al.*, 2005).

As reviewed by Sumaya-Martinez *et al.* (2005), the Maillard reaction links the carbonyl group of the reducing carbohydrates and the amino group of free amino acids as well as of lysyl residues in proteins. This process is classified as non-enzymatic browning reactions and has been associated with the formation of compounds with strong radical scavenging activity. The Maillard reaction takes place in three major stages, as reviewed by Sumaya-Martines *et al.* (2005):

- At an early stage of the reaction, the free amino group of proteins such as the ϵ -NH₂ groups of lysine, react with carbonyl groups of sugars to form a reversible Schiff base, which rearranges to stable, covalently bonded Amadori products. The radical scavenging activity is derived from the uncoloured pigments.
- At intermediate stages, highly UV-absorbing and colourless compounds are continually formed. In the advanced phase of the reaction, Amadori products undergo further transformation to fluorescent, coloured substances and cross-linked polymers.
- Formation of melanoidins and heterocycles compounds in the advanced stage of the Maillard reaction could explain the ability of glycated hydrolysate to react with radical compounds.

Maillard reactions in model systems lead to the formation of different chemical species, it promotes changes in antioxidant properties, which are positively correlated with the development of browning (Manzocco, *et al.*, 2001).

1.8 CONCLUSION

Horticultural products are alive and this means they have biochemical reactions taking place inside them e.g. respiration. These reactions are mainly enzymatic and they use a

lot of carbohydrates as substrates to give off energy that is used by the cells in other reactions. The difference between the product that is still on the tree and the one that has been harvested is as follows:

- Pre-harvest, the carbohydrates are supplied by the mother plant to the fruit, which means less damage to the fruit, while the reserves in the harvested fruit are finite, which means these reactions cause more damage to the fruit post harvest (Kays *et al.*, 2004).

Over and above the natural deterioration due to biochemical reactions taking place inside the harvested fruit, harvested fruits are prone to pathogen attack and damage due to different environmental conditions. Pathogens cause decay of the products; high temperatures promote moisture loss and together with high moisture provide a conducive environment for the pathogens. The main aim of postharvest handling is to retain and deliver to the consumer the products that are still at their best quality (both cosmetic and eating quality).

Cooling provides an active and effective way to reduce the senescence (biochemical reactions) of the product (Arin *et al.*, 2004) and retards the growth of many decay organisms (pathogens) during storage and transport of the fresh produce (Mitchell, 1987). This process of cooling thus retains freshness and quality of the produce, which in turn ensures customer satisfaction. Pre-cooling, which is defined as the process of removing field heat from freshly harvested produce to slow down metabolism and deterioration prior to produce storage or transport (Brosnan *et al.*, 2001), is one of the most important and effective methods to bring the fruit temperature to the levels where most pathogen growth and the biochemical processes are retarded.

There are different methods (modes) that are being utilised to pre-cool horticultural produce. These include room cooling, forced air cooling, contact icing and hydro-cooling (Wills *et al.*, 1989). These modes of cooling use different media to cool down the produce. Room cooling and forced air cooling use air as a cooling medium, contact icing uses ice, while hydro-cooling makes use of water as a cooling medium (Wills *et al.*, 1989). Forced air-cooling is the main method that is being utilised in the fruit industry

and this is due to the ease and practicality of this method. Hydro-cooling is the most effective, but its limitation is the fact that it requires water resistant packaging, and also the fact that free water provides a conducive environment for the pathogens. Water is also a scarce resource in some areas, which makes water very expensive.

For cooling to be effective, a good and effective temperature management is of utmost importance. In a good cold store, the temperature should not exceed 1°C above and below the nominal storage temperature (Wills *et al.*, 1989). Poor temperature management increases the cooling times (in the case of pre-cooling) and compromises the whole purpose of cooling. Warming promotes decay and water loss, whilst lower temperature may freeze the fruits. Poor temperature management may also cause temperature related disorders, including chilling injury, lipid peroxidation, and increased membrane permeability and these in turn result in membrane leakage and fruit browning due to phenolic oxidation by PPO.

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**ARTICLE I: THE EFFECTS OF PRE-COOLING AND POSITIONS IN THE
PRE-COOLING STACK AND REEFER CONTAINER ON THE
QUALITY OF TABLE GRAPES**

ABSTRACT

Various quality variables such as the overall appearance, stem dryness, stem browning, SO₂ burn, decay, berry skin browning, berry flesh browning and berry shatter strongly influence the market perception and acceptance of table grapes. The poor management of the cold chain usually affects these variables negatively as the grapes go through to different markets. 'Victoria' and 'Regal Seedless' table grapes were pre-cooled (using forced air cooling) to target pulp temperatures of -0.5 °C, 1.5 °C and 3 °C and then were shipped at a temperature of -0.5 °C to Rotterdam where they were evaluated for quality. The effects of various positions in a pre-cooling stack and the reefer container on the market quality were studied. Some of the results obtained in both 2005/2006 and 2006/2007 seasons showed that the stems of the grapes that were placed in the middle and in the rear positions in both the pre-cooling stacks and the reefer containers were significantly less dry and less brown than the stems of the grapes that were placed in the front position near the cooling fans and near the reefer cooling units. Some results showed that there was some development of berry flesh browning in the grapes that were placed in the front positions in both the pre-cooling stack and in the reefer container. In the 2006/2007 season, the amount of 'Victoria' berry shatter was significantly less in the front and rear positions than in the middle position in the one reefer container. There were no significant differences observed in the other quality variables that could be ascribed due to the different positions in the pre-cooling stacks or reefers.

Keywords: Pre-cooling, 'Victoria', 'Regal Seedless', stem dryness, stem browning, vapour pressure deficit, water loss, berry browning (discolouration).

INTRODUCTION

Cooling and proper cold chain management are the most commonly used methods to control postharvest ripening and senescence of vegetables and fruits (Arin *et al.*, 2004). Pre-cooling is defined in many ways (review by Brosnan *et al.*, 2001), but it is effectively an active removal of field heat from freshly harvested produce. As product temperature increases, the rate of many biochemical reactions such as respiration also increases logarithmically (Kays *et al.*, 2004). It is these biochemical reactions that result in the loss of pre-harvest quality of harvested horticultural products when they reach the distant markets. These biochemical reactions are retarded at low temperatures (Arin *et al.*, 2004), which is why pre-cooling is widely regarded as the most important of all the operations used in the maintenance of desirable, fresh and saleable produce. Table grapes and many other horticultural products are susceptible to deterioration after harvest. The reasons why table grapes and probably many other horticultural products should be cooled thoroughly are: to minimize water loss from the fruit, to retard development of decay caused by fungi, and to reduce the rate of respiration (Nelson, 1978).

Water loss from horticultural products impacts on quality parameters such as the appearance and fruit texture (Paull, 1998). Water loss is strictly a physical factor related to the evaporative potential of the surrounding air (Nelson, 1978). The water vapour pressure deficit (WVPD) is the difference between actual vapour pressure (RH and temperature dependant) and the saturated vapour pressure and determines the rate of evaporation from a fresh commodity at the same temperature (Paull, 1998). RH is dependant on the surface area of the refrigeration evaporator coil in the storage room and temperature difference between the coil and the air, along with air exchange rates, temperature distribution in the room, commodity and packing material used (Paull, 1998). High RH will not prevent moisture loss if the product temperature is not near the air temperature (Paull, 1998). It is to be expected then that the VPD would be especially high during the typically hot, dry conditions that prevail during harvest of table grapes.

Temperature affects the rate of growth and spread of decay organisms in the same way that it affects the commodity – the lower the temperature, the slower the rate of life processes (Mitchell, 1987). Certain disease organisms will not grow at ideal fruit storage temperatures, with the exception of a few organisms, notably *Botrytis cinerea* (Mitchell, 1987). Low temperatures do not prevent the germination of *Botrytis* spores, but merely delay it (Ginsburg *et al.*, 1978). *Botrytis* spores will germinate when free moisture or very high relative humidity conditions prevail (Ginsburg *et al.*, 1978). Prompt, thorough cooling is thus essential to minimise the problems of fruit decay during transport and distribution.

Temperature has a pronounced effect on the respiratory rate of harvested products. As product temperature increases, the rate of biological reactions like respiration increase logarithmically (Kays *et al.*, 2004). For every 10 °C rise in temperature, the rate of respiration is roughly doubled or tripled (Hardenburg *et al.*, 1986). The change in rate with temperature follows van't Hoff's rule fairly closely, which states that the rate of most chemical and biochemical reactions increases two to three times with every 10 degrees rise in temperature. For example, an apple held at 10 °C ripens and respire about three times as fast as one held at 0 °C, and one held at 20 °C respire about three times as fast as at 10 °C (Hardenburg *et al.*, 1986). Prompt, thorough cooling is also imperative to reduce the product respiration. During the process of respiration, energy is released in the form of heat (Hardenburg *et al.*, 1986). This heat adds an extra heat load that needs to be removed during storage and transport of horticultural products to the markets (Hardenburg *et al.*, 1986). Proper temperature management is thus required throughout the entire cold chain to ensure proper cooling of the products.

South African table grapes are pre-cooled to a statutory pulp temperature of -0.5°C prior to shipping to the overseas markets. The nature of cooling is such that the rate of cooling declines as product temperature approaches the temperature of the cooling medium (Thompson *et al.*, 1998). Therefore, a disproportionate amount of time is spent in removing the last few degrees of field heat from the product. This delay significantly reduces the throughput of the cold rooms. This research was conducted to investigate

whether table grapes could be forced air cooled to higher end-point temperatures than currently used, and shipped at the recommended delivery air temperature of -0.5°C without quality loss.

MATERIALS AND METHODS

Season 1: 2005/2006

The project was conducted on a commercial scale, as it is impossible to simulate exactly the conditions in pre-cooling tunnels and reefer shipping containers. Additionally, it was felt that potential commercial implementation of the results would require commercial-scale trials. The trials were conducted in consecutive seasons in the Lower Orange River and De Doorns areas, covering early, dryer and late, wetter production zones, respectively. In the Orange River the grapes ('Victoria') were sourced and packed at AAA Trust and pre-cooled at Augpad cooling facilities. In De Doorns the grapes ('Regal Seedless') were sourced and packed at Wolwehoek Trust and pre-cooled at Hexkoel.

The grapes were commercially ripe (14°Brix - 'Victoria' and 18°Brix - 'Regal Seedless'). 'Victoria' grapes were packed in commercial 4.5 kg cartons that were lined with 2 mm perforated liners. The grape bunches were packed in polycote bags and were covered with commercially used Uvays SO_2 pads to control *Botrytis cinerea*. 'Regal Seedless' grapes were packed in commercial 5 kg cartons that were lined with 4 mm perforated liners. The grape bunches were packed in punnets and were covered with a commercially used Uvays SO_2 pads to control *Botrytis cinerea*.

The pulp temperature during pre-cooling was monitored with thermocouple wires until the target pulp temperature was reached. During packing Thermocron® iButton® (DS1921Z-F5) temperature loggers (supplied by Dallas Semiconductor, iButton Product Group, Dallas, Texas) were also used to measure both the air and pulp temperatures throughout the cold chain in order to make comparisons with the thermocouple readings. To measure the pulp temperature extra large 'Red Globe' berries were cut in half in a

longitudinal section with a sharp knife, then the vascular tissue with a bit of pulp was removed carefully to create room for the placement of the button inside the berries. Once each button was carefully placed inside the berries, the two halves of the berries were replaced back into position, enclosing the 'Thermocron' button inside the berry. A rubber band was used to seal the two halves of the berry together. The 'Red Globe' berries were used for easy identification amongst the white berries. The berries with the buttons were placed in between the berries of bunches in the polycote bag ('Victoria') and in punnets ('Regal Seedless') inside the cartons. To measure the air temperature inside the cartons the 'Thermocron' button was attached on the outside of the polycote bag ('Victoria') with a strip of adhesive tape, while for 'Regal Seedless' the buttons were loosely placed in the punnets. Temperatures were recorded in the 4th, 10th and 16th layers from the pallet base, in three cartons per layer of each experimental pallet. There were two buttons in each of the three cartons per layer, one in the 'Red Globe' berry to measure pulp temperature and the other one was hung with an adhesive tape to measure air temperature in the carton. The buttons were distributed in each layer as per figures 1 and 2.

During pre-cooling 20 pallets each were pre-cooled to pulp temperatures of -0.5°C (control), 1.5°C and 3°C, in three different cooling tunnels with the same delivery air temperature (DAT) respectively. These target temperatures were monitored with the commercially used thermocouple wires inserted into a berry in the centre of each pallet. When the target pulp temperature was reached twenty pallets were loaded into each of 3 reefer containers set at -0.5°C. The experimental pallets were distributed both in the cooling tunnels and in the reefer containers to account for the temperature gradients within these units. At Augpad cooling tunnels three experimental pallets were placed in the front of the stack (near the pre-cooling fan), three in the middle of the stack and three at the end of the stack (warm position of the stack). Likewise in the reefer containers, three pallets were placed in front (coolest position, near the cooling unit), three in the middle and three at the back of the container (warmest position, near the doors). One pallet from each of the three tunnel positions was placed in the front, middle and back of each reefer. Therefore, all permutations of coolest-, intermediate- and warmest tunnel positions with coolest-, intermediate- and warmest reefer positions were covered. At

Hexkoel, the pre-cooling fans are situated on the roof of the tunnels and therefore the temperature gradient along the length of the tunnels is regarded negligible. Therefore, the pallets were placed randomly in the tunnels. However, in the reefer containers three experimental pallets were placed in front (near the cooling unit), three in the middle and three at the back of the container (near the doors).

The loaded containers were transported to the port under generator power, and upon their arrival in the terminal they were plugged in stacks until time of shipment. Upon arrival in the EU (Rotterdam), the nine experimental pallets from each container were collected and broken down to retrieve all the marked experimental cartons and the Thermocron buttons. The grapes from each experimental carton (three per layer and three layers per pallet) were inspected for quality upon arrival and again after 3-4 weeks of additional cold storage. The grapes were evaluated for the following quality variables and as follows: overall appearance (App) of the grapes (1 = excellent; 2 = good; 3 = acceptable; 4 = poor and 5 = very bad), stem browning (StmB) (1 = fresh and green stems; 2 = some light browning; 3 = significant browning; 4 = severe browning), dry stems (DryStm) (1 = fresh stems, no dry stems; 2 = some drying of thinner stems; 3 = all thinner stems dry; 4 = all thinner stems and some thicker stems dry; 5 = all stems dry), SO₂ damage (SO₂B) (1 = none; 2 = slight damage (<5%); 3 = moderate damage (5-10%); 4 = severe damage (>10%)), decay (1 = none; 2 = slight (<2 infected berries per carton); 3 = severe (2 – 5 infected berries); 4 = extreme (>5 infected berries per carton)), berry skin browning (BrySB) (1 = no browning; 2 = < 5% browning; 3 = 5-10 % browning; 4 = 11-20% browning; 5 = > 20% browning), berry flesh browning (BryFB) (1 = no browning; 2 = < 5% browning; 3 = 5-10 % browning; 4 = 11-20% browning; 5 = > 20% browning) and berry shatter (Bshatter) (1 = no loose; 2 = < 10 loose berries per carton; 3 = 10-20 loose berries per carton; 4 = > 20 loose berries per carton). Each experimental carton was a complete sample, meaning percentages for example, were expressed as a mass of berries with defects over total mass of a packed carton.

Season 2: 2006/2007

During the 2006/2007 season the trials were repeated to validate the results obtained in the previous season. During this season two additional trials were added, and these included the use of non-perforated liners.

Statistical analysis

There were three treatments namely: front (near cooling fans), middle and rear (near the pre-cooling room door) positions in the pre-cooling stack. In each position (treatment) there were three experimental pallets, making a total of 9 experimental pallets per stack. The positions in the reefer containers were divided into three blocks due to the temperature gradient from the front (near cooling unit) through to the rear (near doors). Block 1 was front position in the reefer container, block 2 was the middle and block 3 was in the rear position. All the treatments were allocated to each block. Due to the fact that this trial was conducted on a commercial scale, with resulting limitations on treatment replications and randomisation, the interaction effects between the positions in the stack and reefer container could not be analysed. This means that the interactions formed part of the error term. Statistical Analyses System (SAS), Enterprise Guide was used to determine the analysis of variance (ANOVA) and LSD values with a 5% significance level. The effect of pre-cooling (FAC) to different pulp temperatures (-0.5 °C, 1.5 °C and 3 °C) on the quality of grapes could not be analysed statistically due to the impracticality of having enough replications in this commercial trial. However, the LS means with standard errors were compared to see if there were any trends and differences between the three FAC treatments. The effects of perforated and non-perforated liners were regarded as separate trials and therefore analysed independently from each other.

RESULTS

2005/06 season:

'Victoria' grapes pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (arrival), $1.5\text{ }^{\circ}\text{C}$ (4 weeks after arrival) and $3\text{ }^{\circ}\text{C}$ (4 weeks after arrival): There were no significant differences that were observed in the measured quality variables that were due to the different positions in the pre-cooling stack or in the reefer container (data not shown).

'Victoria' grapes pre-cooled to $1.5\text{ }^{\circ}\text{C}$ (arrival): There were no significant differences in the quality variables that were due to the different positions in the pre-cooling stack (Table 1). However, in the reefer container, the stems were significantly ($P = 0.0002$) less brown in the middle and rear positions than in the front position. Stems were also significantly ($P = 0.0342$) less dry in the middle and in the rear positions than in the front position in the reefer container. There were no significant differences in terms of stem condition between the middle and the rear positions in the reefer container. There were also no significant differences in the other quality variables that were due to the different positions in a reefer container.

'Victoria' grapes pre-cooled to $3\text{ }^{\circ}\text{C}$ (arrival): The amount of berry flesh browning was significantly ($P = 0.0421$) less on the grapes placed in the back position in the pre-cooling stack than the grapes that were placed in the front and in the middle positions in the pre-cooling stack (Table 2). The overall appearance of the grapes that were placed at the back in the stack was significantly ($P = 0.0148$) better than the appearance of the grapes that were placed in the front and in the middle positions in the pre-cooling stack. There were no significant differences in the quality variables ascribed to the different positions in the reefer container (Table 2).

'Victoria' grapes pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (4 weeks after arrival): The stems of the *'Victoria'* grapes that were placed in the back position in the pre-cooling stack were significantly less dry ($P = 0.0252$) than the grapes that were placed in the front and in the

middle positions in the stack (Table 3). There were no significant differences that were observed in the other quality variables ascribed to the positions in the pre-cooling stack. There were no significant differences observed in the quality variables that were due to the different positions in the reefer container.

'Regal Seedless' grapes pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (arrival): The stems of the 'Regal Seedless' positioned at the rear in the reefer container were significantly ($P = 0.0158$) less brown than the stems of grapes that were placed at the front and middle positions in the reefer container (Table 4). There were no significant differences in the stem browning between the front and middle positions.

'Regal Seedless' grapes pre-cooled to $1.5\text{ }^{\circ}\text{C}$ and $3\text{ }^{\circ}\text{C}$ (arrival): There were no significant differences in the quality variables that were due to the different positions in the reefer container (data not shown).

2006/07 season:

Grapes packed in perforated liners

'Victoria' grapes pre-cooled to $3\text{ }^{\circ}\text{C}$ (arrival), $-0.5\text{ }^{\circ}\text{C}$ (4 weeks after arrival), and $1.5\text{ }^{\circ}\text{C}$ (4 weeks after arrival): There were no significant differences observed in the quality of grapes from the different positions in a pre-cooling stack and in the reefer container (data not shown).

'Victoria' grapes pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (arrival): There were no significant quality differences due to stack positions (Table 5). The stems of the grapes that were placed in the middle and the rear positions in the reefer container were significantly less brown ($P = 0.0114$) and less dry ($P = 0.0494$) than the stems of the grapes that were placed in the front position in the reefer container.

'Victoria' grapes pre-cooled to 1.5 °C (arrival): There were no significant quality differences due to the stack positions (Table 6). The stems of the grapes placed in the middle and the rear positions were significantly less dry ($P = 0.0055$) than the stems of the grapes placed in the front position in the reefer container.

'Victoria' grapes pre-cooled to 3 °C, (4 weeks after arrival): There were no significant differences observed on the measured quality variables that were due to the different positions in a pre-cooling stack (Table 7). The stems of grapes placed in the middle position in the reefer container were significantly less brown ($P = 0.0494$) and less dry ($P = 0.0230$) than the stems of the grapes that were placed in the front and the rear positions.

'Regal Seedless' grapes pre-cooled to -0.5 °C, 1.5 °C, 3 °C (arrival) and -0.5 °C and 1.5 °C (4 weeks after arrival): There were no significant differences in the quality variables that were due to the positions in the reefer container (data not shown).

'Regal Seedless' grapes pre-cooled to a pulp temperature of 3 °C (4 weeks after arrival): The number of berries that developed flesh browning was significantly less ($P < 0.0001$) in the grapes placed in the middle and rear positions than the grapes placed in the front position in the reefer container (Table 8).

Grapes packed in non-perforated liners

'Victoria' grapes pre-cooled to -0.5 °C and 1.5 °C (arrival) and grapes pre-cooled to -0.5 °C and 3 °C (4 weeks after arrival): There were no significant differences observed in the quality of grapes from the different positions in a pre-cooling stack and in the reefer container (data not shown).

'Victoria' grapes pre-cooled to 3 °C (arrival): There were no significant differences in the quality variables that were due to the different positions in a pre-cooling stack (Table 9). The stems of grapes placed in the rear position in the reefer container were

significantly less brown ($P = 0.0434$) than the stems of the grapes placed in the front position in reefer container.

‘Victoria’ grapes pre-cooled to 1.5 °C (4 weeks after arrival): The stems of grapes placed in the back position in the pre-cooling stack were significantly less dry ($P = 0.0494$) than the stems of the grapes placed in the front position in the stack (Table 10). The amount of berry shatter was significantly less ($P = 0.0077$) in the grapes placed in the front and the rear positions in the reefer container than the grapes placed in the middle position.

‘Regal seedless’ grapes pre-cooled to a pulp temperature of -0.5 °C, 1.5 °C, 3 °C (arrival) and -0.5 °C and 3 °C (4 weeks after arrival): There were no significant differences in the quality variables that were due to the positions in the reefer container (data not shown).

‘Regal seedless’ grapes pre-cooled to a pulp temperature of -0.5 °C (4 weeks after arrival): The stems of the grapes placed in the front and the rear positions in the reefer container were significantly less dry ($P = 0.0007$) than the stems of the grapes placed in the middle position (Table 11).

The effect of forced air-cooling to pulp temperatures of -0.5 °C, 1.5 °C and 3 °C on the quality of ‘Victoria’ and ‘Regal Seedless’:

i. Perforated liners

Forced air-cooling of ‘Victoria’ (Table 12) and ‘Regal Seedless’ (Table 13) table grapes to pulp temperatures of 3 °C resulted in better quality at arrival, in comparison to the grapes cooled to a pulp temperature of 1.5 °C and -0.5 °C in terms of the stem browning, dry stems and decay. This was true for both seasons 2005/06 and 2006/07. There was not much difference in terms of SO₂ damage. Berry skin and flesh browning varied between the two seasons indicating that these defects were not necessarily due to FAC treatments. In ‘Victoria’ grapes FAC to 1.5 °C resulted in less berry shatter than FAC to -0.5 °C and

3 °C, while in ‘Regal Seedless’ (2005/06 season) FAC to 3 °C resulted in the least berry shatter whilst in the 2006/07 season it resulted in the most shatter.

ii. Non-perforated liners

‘Regal Seedless’ showed better quality when FAC to 1.5 °C and 3 °C than when FAC to –0.5 °C in terms of overall appearance, stem browning, dry stems and berry skin and flesh browning (Table 14). There were no differences in SO₂ damage and decay between the three FAC treatments. There was more berry shatter on the grapes FAC to 3 °C and no berry shatter on grapes FAC to –0.5 °C and 1.5 °C. ‘Victoria’ had better quality when FAC to 1.5 °C in terms of overall appearance, stem browning, dry stem and berry shatter (Table 15). There was no difference in SO₂ damage between the treatments. There was no decay on the grapes FAC to 1.5 °C and 3 °C, but there was decay on the grapes FAC to –0.5 °C. There was no berry flesh browning on the grapes FAC to 3 °C, whilst browning was evident in grapes FAC to –0.5 °C and 1.5 °C (Tables 14 and 15).

Pulp temperature readings and cooling time

The pulp temperature readings measured with the commercially used thermocouples and the handheld KM 22 “Food Check” instrument were compared to those measured with the Thermocron iButtons, at the termination of forced air cooling at Augpad cooling facilities. On average there was a 1.60 °C difference between the two measuring equipments, with the Thermocron iButtons showing higher pulp temperatures than the thermocouples (Table 16). On average the target pulp temperature of 3 °C was reached in 16 hours of FAC, while the pulp temperature of 1.5 °C was reached in 36 hours and the pulp temperature of –0.5 °C was reached in 40 hours (data not shown). The cooling time that was saved by cooling table grapes to higher pulp temperatures of 1.5 °C and 3 °C was 4 hours and 24 hours, respectively.

DISCUSSION

Stem condition (dryness and browning)

Nelson (1979) describes the symptoms of water loss in table grapes in three stages. First to appear are shriveled stems that usually become brittle and break easily when handled. The second symptom of water loss to appear is browning of the stems. The third symptom of water loss is shrinkage of the berries. Nelson (1979) further states that grape berries do not show symptoms of water loss until shrinkage is quite evident on the stems. However, at about 3 % loss in weight, the berries start to appear dull as the taut condition of the skin slackens (Nelson, 1979). At 4 to 5 % loss the berries feel definitely soft, and above a 5 % loss fine wrinkles start to appear radiating out from the pedicel (Nelson, 1979). The rate of stem dryness, stem browning and subsequent berry shriveling are related to high temperatures. Water is lost from produce in the form of water vapour (Thompson *et al.*, 1998). Fruits and vegetables are composed of cells loosely bound together, with a considerable amount of interconnecting intercellular spaces that lead to natural openings and wounds. Water from the cells vaporizes into the intercellular space and maintains a nearly saturated atmosphere within the product. Water vapour moves to the outside atmosphere through lenticels, stomates, stem scars, injured areas, or directly through the cuticle (Thompson *et al.*, 1998).

It was interesting to see in some of the results obtained in 2005/2006 season that there were significant differences in terms of stem dryness and stem browning that were due to the different positions in the reefer container and the different positions in the pre-cooling stack in both the 'Victoria' and 'Regal Seedless'. The stems of table grapes placed in the middle and the rear position in the reefer container (Tables 1 and 4) were significantly less dry and less brown than the stems of table grapes placed in the front position in the reefer container. Table 3 shows that 4 weeks after arrival, the stems of the Victoria grapes that were placed in the back position in the pre-cooling stack developed less stem browning than those that were placed in the front and in the middle positions in the pre-cooling stack. The trends observed in some of the results that were obtained in the

2006/2007 season (tables 5, 6, 7, 9 and 11) on the grapes were similar to the trends observed in the 2005/2006 season.

Thompson *et al.* (1998) and Nelson (1978) state that fruit water loss is due to vapour pressure deficit (Vpd), which is the evaporative potential of the surrounding environment where the fruits are kept. The vapour pressure deficit increases with an increase of temperature of the surroundings where fruit is kept. The results showed an opposite of the vapour pressure deficit equation. This means that these results may be due to the uneven distribution of air flow in the pre-cooling rooms and in the reefer containers rather than the temperature. The uneven distribution of the airflow results in turbulence in certain areas within the loads (Smale *et al.*, 2006). The air turbulence may be responsible for the removal of moisture in the perforated liners leaving dryer conditions in the fruit surroundings (in the cartons) and thus the moisture evaporates from the grape stems into the cartons. Smale *et al.* (2006) reviewed, amongst other models, the turbulence models. They stated that many refrigerated transport and storage facilities can be considered as slot-ventilated enclosures, where turbulent flows are obtained by injection of a jet of high velocity air adjacent and parallel to the ceiling (Smale *et al.*, 2006). The complexity of the system is increased by the presence of the load, which increases the confinement effect and the adverse pressure gradient. Pallets and boxes affect the airflow through surface stresses, porous infiltration, deviations and reattachment and also turbulence generation. They may create secondary recirculating flows, including stagnant zones and induce high velocities elsewhere (Moureh *et al.*, 2002; Smale *et al.*, 2006). From an aerodynamic perspective, the key characteristic of transport equipment is the placement of both the air delivery and return units on the same face (Smale *et al.*, 2006). This configuration is almost universally used, as it is practical to place all the refrigerating equipment at one end of the transport unit (Smale *et al.*, 2006). The drawback of this asymmetrical design is the presence of a strong pathway between the two sections, implying high velocities in the front of the refrigerated enclosure (Smale *et al.*, 2006). In addition, the compactness of the cargo and high resistance to airflow due to narrow air spaces between pallets result in an uneven air distribution in the cargo where stagnant

zones with poor ventilation can be observed in the rear part of the vehicle (Smale *et al.*, 2006).

Berry shatter

Berry shatter is as a result of excessively dry stems. Table 10 shows that 4 weeks after arrival, the 'Victoria' table grapes that were pre-cooled to a pulp temperature of 1.5°C and packed in a non-perforated liner showed more berry shatter. The grapes that were placed in the middle position in the reefer container showed more berry shatter than the grapes that were placed in the front and rear positions in the reefer container. Although the stem condition (stem dryness and stem browning) between the three positions in the reefer were not significantly different, the means show that there was more stem dryness and more stem browning on the 'Victoria' grapes that were placed in the middle position in the reefer container than the grapes that were placed in the front and rear positions in the reefer container. The poorer stem condition obviously resulted in more shatter on the grapes that were placed in the middle position in the reefer container.

Berry Browning (Discolouration)

Fruit browning has been widely described as one of the symptoms of chilling injury (Bramlage *et al.*, 1990; Jiang *et al.*, 2004). The process of fruit browning can either be enzymatic or non-enzymatic. Enzymatic browning is the most common in fruits, and is catalysed by the enzyme polyphenol oxidase (PPO) (Valentines *et al.*, 2005). Enzymatic browning is due to a lack of compartmentation within the cell. The breakage of the tonoplast results in phenolics being exposed to PPO. In some fruits this damage is due to chilling injury (Jiang *et al.*, 2004). The results in tables 2 and 10 show that the 'Victoria' and 'Regal Seedless' grapes that had some berry flesh browning were placed in the front position in the pre-cooling stack and in the front position in the reefer container, respectively. These positions are regarded as the coldest positions because in the pre-cooling stack they are near the fans, while in the reefer container they are close to the

refrigeration unit where the delivery air comes in to the cargo. The browning that was observed might have developed from chilling injury of these grapes in these positions.

Pulp temperature readings and cooling time

The problem with the Thermocouple wires is the fact that most of the time the packhouse workers do not insert the wires properly into the fruit when they build up the pallets. This results in the false temperature readings by the thermocouple and this jeopardizes the proper temperature management during cooling and shipping of fruits. The reason for the higher readings by the Thermocron buttons in comparison to the thermocouple readings may have been due to the fact that temperature was measured at three different points (as shown in Figures 1 and 2) with the Thermocron buttons, then an average temperature reading of the three points was calculated, while the thermocouple measured only a single point, which is the center of the pallets. There is then a possibility that at least one of the three points measured by the Thermocron buttons may have had a much higher reading than the thermocouple, therefore leading to a higher average reading. This contention is supported by work of Leuvenink and Moelich (2004). They found that pulp temperature increased across the width of the pallet from the outermost to the innermost cartons in the FAC tunnel, with temperature differences of up to 10°C. Cooling grapes to higher endpoint temperature of 3°C resulted in a saving of 24 hours cooling time. It took 16 hours to cool down grapes to 3°C, while it took 40 hours to cool them down to -0.5°C. Cooling grapes to 1.5°C took 36 hours, which means only 4 hours cooling time was saved. Cooling time was shortened significantly by FAC to 3°C compared to FAC to 1.5°C. This means greater throughput of the cold rooms and some power saving for the cooling facilities.

CONCLUSION

Based on the results obtained in this study, it was clear that the location of a pallet in the pre-cooling stack and reefer container has a large influence on the conditions to which the pallet is exposed (temperature, airflow and perhaps also RH), as manifested in the fruit

quality. In some cases there were significant differences in some measured variables that were due to the different positions in the pre-cooling stack and in some cases there were no significant differences. Also in some reefer containers some significant differences were observed in the measured variables that were due to the different positions and in some containers there were no differences.

In cases where there were significant differences in the measured variables, the middle and the rear positions generally showed better quality of table grapes than the front position in both the pre-cooling stack and in the reefer containers. This indicates that the warmer positions tended to result in better fruit quality.

Cooling grapes to 3°C means a full day of cooling time may be saved by the cooling facilities, while cooling to 1.5°C means saving cooling time by 4 hours in comparison to cooling to -0.5°C. Therefore, cooling grapes to higher pulp temperatures than the current statutory temperature means after every 16 hours (in case of cooling to 3°C) of cooling, a new load of warm pallets enters the cold room and this improves the throughput of the cold rooms greatly. Care must be taken though by the cooling facilities not to cool grape to pulp temperatures greater than 3°C (as monitored by thermocouple wires).

Both 'Victoria' and 'Regal Seedless showed better quality when FAC to 1.5 °C and 3 °C in comparison to FAC to -0.5 °C. There were no economic losses associated with pre-cooling the grapes to pulp temperatures of 1.5 °C and 3 °C in comparison to those cooled to the statutory pulp temperature of -0.5 °C. The pack house managers need to train the workers on how to insert Thermocouple wires properly and the importance of the Thermocouples in the entire cold chain. Based on the results, it can be recommended that the statutory pulp temperature be raised to at least 1.5 °C to 2 °C for table grapes. This might improve the throughput in the cold rooms by significantly saving on pre-cooling time. However, factors such as rain before harvest and decay pressure need to be considered before applying such measures.

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Table 1: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 1.5°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.3667	1.30000	2.9333	1.03333	1.03333	1.2667	1.1000	1.6333
Middle of stack	1.8100	1.26667	3.3333	1.00000	1.00000	1.1667	1.1000	1.6333
Back of stack	2.1667	1.40000	3.1000	1.03333	1.03333	1.2667	1.2000	1.6333
LSD	0.7599	0.1195	1.0579	0.0756	0.1195	0.7798	0.3463	0.8174
<i>Pr > F</i>	0.2353	0.0772	0.6122	0.4444	0.6944	0.9206	0.6782	1.0000
Container position								
Front of container	2.5333	1.73333 a	4.0000 a	1.00000	1.03333	1.0000	1.3000	1.5000
Middle of container	1.7767	1.16667 b	2.9333 b	1.00000	1.03333	1.3333	1.0333	1.6000
Rear of container	2.0333	1.06667 b	2.4333 b	1.06667	1.00000	1.3667	1.0667	1.8000
LSD	0.7599	0.1195	1.0579	0.0756	0.1195	0.7798	0.3463	0.8174
<i>Pr > F</i>	0.1129	0.0002	0.0342	0.1111	0.6944	0.4322	0.1800	0.6208

^aRating where 1 = excellent; 2 = good; 3 = acceptable; 4 = poor and 5 = very bad

^bRating where 1 = fresh and green stems; 2 = some light browning; 3 = significant browning; 4 = severe browning

^cRating where 1 = fresh stems, no dry stems; 2 = some drying of thinner stems; 3 = all thinner stems dry; 4 = all thinner stems and some thicker stems dry; 5 = all stems dry

^dRating where 1 = none; 2 = slight damage (<5%); 3 = moderate damage (5-10%); 4 = severe damage (>10%)

^eRating where 1 = none; 2 = slight (<2 infected berries per carton); 3 = severe (2 – 5 infected berries); 4 = extreme (>5 infected berries per carton)

^fRating where 1 = no loose; 2 = < 10 loose berries per carton; 3 = 10-20 loose berries per carton; 4 = > 20 loose berries per carton

Table 2: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 3°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.6100 a	1.3667	2.8433	1.03333	1.17667	1.1000	1.30000 a	1.8667
Middle of stack	2.4000 a	1.1000	3.0000	1.00000	1.03333	1.2767	1.33333 a	2.1000
Back of stack	2.0333 b	1.0000	2.3667	1.00000	1.00000	1.1333	1.13333 b	1.7767
LSD	0.3017	0.8415	2.2238	0.0756	0.2660	0.2801	0.1511	0.3017
<i>Pr > F</i>	<i>0.0148</i>	<i>0.5167</i>	<i>0.7310</i>	<i>0.4444</i>	<i>0.2603</i>	<i>0.2873</i>	<i>0.0421</i>	<i>0.0889</i>
Container position								
Front of the container	2.4667	1.4000	3.1333	1.00000	1.00000	1.2667	1.30000	1.8667
Middle of container	2.3000	1.0667	3.0767	1.00000	1.17667	1.2100	1.26667	2.1000
Rear of container	2.2767	1.0000	2.0000	1.03333	1.03333	1.0333	1.20000	1.7767
LSD	0.3017	0.8415	2.2238	0.0756	0.2660	0.2801	0.1511	0.3017
<i>Pr > F</i>	<i>0.2743</i>	<i>0.4444</i>	<i>0.3738</i>	<i>0.4444</i>	<i>0.2603</i>	<i>0.1659</i>	<i>0.2844</i>	<i>0.0887</i>

^{a-f} “Ratings, as defined in Table 1”.

Table 3: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to -0.5°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.8777	2.4443	4.4557 a	1.00000	1.10000	1.03333	1.3667	2.7000
Middle of stack	2.8110	2.2110	4.1887 a	1.03333	1.06667	1.00000	1.3443	2.7000
Back of stack	2.3330	1.9333	3.6000 b	1.00000	1.03333	1.00000	1.3333	2.6000
LSD	0.6361	1.1989	0.5282	0.0756	0.1851	0.0756	0.7110	0.8261
<i>Pr > F</i>	0.1390	0.5479	0.0252	0.4444	0.6400	0.4444	0.9913	0.8995
Container position								
Front of container	2.9443	2.2557	4.0777	1.00000	1.06667	1.03333	1.2557	2.5223
Middle of container	2.8220	2.7777	4.3443	1.00000	1.10000	1.00000	1.5667	2.7667
Rear of container	2.2553	1.5553	3.8223	1.03333	1.03333	1.00000	1.2220	2.7443
LSD	0.6361	1.1989	0.5282	0.0756	0.1851	0.0756	0.7110	0.8261
<i>Pr > F</i>	0.0783	0.1098	0.1204	0.4444	0.6400	0.4444	0.4159	0.6874

^{a-f} “Ratings, as defined in Table 1”.

Table 4: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes pre-cooled to -0.5 °C (2005/06 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	1.00000	2.7037 a	3.7778	1.000	1.03704	1.000	1.000	3.4444
Middle of container	1.07407	2.5926 a	3.6296	1.000	1.00000	1.000	1.000	3.6667
Rear of container	1.00000	1.9630 b	3.0370	1.000	1.00000	1.000	1.000	3.5185
LSD	0.148	0.4621	0.7546	0	0.074	0	0	0.6701
<i>Pr > F</i>	0.4219	0.0158	0.1116	-	0.4219	-	-	0.7237

^{a-f} “Ratings, as defined in Table 1”.

Table 5 : Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to -0.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.3333	2.0000	1.6667	1.000	1.3333	1.0000	1.0000	1.5000
Middle of stack	1.8333	1.5000	1.1667	1.000	1.0000	1.0000	1.0000	2.0000
Back of stack	2.3333	1.8333	1.1667	1.000	1.0000	1.0000	1.1667	2.0000
LSD	1.1335	0.7557	0.6544	0	0.3778	0	0.3778	1.3088
<i>Pr > F</i>	0.4444	0.2844	0.1600	-	0.1111	-	0.4444	0.5289
Container position								
Front of container	2.5000	2.6667 a	1.8333 a	1.0000	1.1667	1.0000	1.0000	1.6667
Middle of container	2.0000	1.1667 b	1.0000 b	1.0000	1.1667	1.0000	1.0000	2.0000
Rear of container	2.0000	1.5000 b	1.1667 b	1.0000	1.0000	1.0000	1.1667	1.8333
LSD	1.1335	0.7557	0.6544	0	0.3778	0	0.3778	1.3088
<i>Pr > F</i>	0.4444	0.0114	0.0494	-	0.4444	-	0.4444	0.7901

^{a-f} “Ratings, as defined in Table 1”.

Table 6 : Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 1.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	1.8333	1.8333	1.3333	1.0000	1.0000	1.0000	1.0000	1.6667
Middle of stack	1.8333	2.0000	1.3333	1.0000	1.0000	1.0000	1.0000	1.5000
Back of stack	1.6667	1.6667	1.1667	1.1667	1.0000	1.3333	1.0000	1.5000
LSD	1.3623	1.4633	0.3778	0.3778	0	0.7557	0	0.7557
<i>Pr > F</i>	0.9273	0.8264	0.4444	0.4444	-	0.4444	-	0.7901
Container position								
Front of container	2.3333	2.5000	1.8333 a	1.1667	1.0000	1.3333	1.0000	1.6667
Middle of container	1.6667	1.6667	1.0000 b	1.0000	1.0000	1.0000	1.0000	1.1667
Rear of container	1.3333	1.3333	1.0000 b	1.0000	1.0000	1.0000	1.0000	1.8333
LSD	1.3623	1.4633	0.3778	0.3778	0	0.7557	0	0.7557
<i>Pr > F</i>	0.2318	0.1890	0.0055	0.4444	-	0.4444	-	0.7901

^{a-f}“Ratings, as defined in Table 1”.

Table 7: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to 3 °C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	3.6667	2.6667	3.6667	1.0000	1.1667	3.3333	1.1667	2.0000
Middle of stack	3.8333	3.1667	3.1667	1.0000	1.0000	3.3333	1.0000	2.1667
Back of stack	3.1667	2.6667	3.0000	1.0000	1.3333	2.0000	1.0000	2.1667
LSD	0.9996	0.6544	1.1948	0	0.9255	1.3623	0.3778	0.5974
<i>Pr > F</i>	0.2689	0.1600	0.3673	-	0.6400	0.0835	0.4444	0.6944
Container position								
Front of container	3.6667	3.1667 a	4.1667 a	1.0000	1.3333	3.1667	1.1667	2.0000
Middle of container	3.3333	2.3333 b	2.1667 b	1.0000	1.0000	2.1667	1.0000	2.1667
Rear of container	3.6667	3.0000 a	3.5000 a	1.0000	1.1667	3.3333	1.0000	2.1667
LSD	0.9996	0.6544	1.1948	0	0.9255	1.3623	0.3778	0.5974
<i>Pr > F</i>	0.6049	0.0494	0.0230	-	0.6400	0.1420	0.4444	0.6944

^{a-f} “Ratings, as defined in Table 1”.

Table 8: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to 3 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	3.0000	2.5000	2.5000	1.0000	1.3333	1.1667	1.5000 a	2.0000
Middle of container	2.8333	3.0000	3.0000	1.0000	1.5000	1.0000	1.0000 b	2.0000
Rear of container	3.1667	2.5000	2.3333	1.0000	1.3333	1.1667	1.0000 b	2.0000
LSD	0.7446	0.8156	0.881	0	0.9418	0.4709	0	2.378
Pr > F	0.5787	0.2963	0.2356	-	0.8847	0.6297	<i>P</i> <0.0001	1.0000

^{a-f} “Ratings, as defined in Table 1”.

Table 9: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 3°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.1667	1.6667	1.1667	1.0000	1.0000	1.8333	1.0000	2.5000
Middle of stack	2.8333	2.0000	1.8333	1.0000	1.0000	2.0000	1.0000	2.0000
Back of stack	2.1667	1.6667	1.3333	1.0000	1.0000	2.0000	1.0000	1.8333
LSD	0.9996	1.1948	1.1015	0	0	0.8861	0	0.8861
<i>Pr > F</i>	0.2178	0.6944	0.3211	-	-	0.8403	-	0.8403
Container position								
Front of container	2.6667	2.6667 a	1.8333	1.0000	1.0000	2.0000	1.0000	2.0000
Middle of container	2.5000	1.6667 ab	1.5000	1.0000	1.0000	1.8333	1.0000	2.1667
Rear of container	2.0000	1.0000 b	1.0000	1.0000	1.0000	2.0000	1.0000	2.1667
LSD	0.9996	1.1948	1.1015	0	0	0.8861	0	0.8861
<i>Pr > F</i>	0.2689	0.0434	0.2230	-	-	0.8403	-	0.8403

^{a-f} “Ratings, as defined in Table 1”.

Table 10: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to 1.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.5000	1.8333	2.3333 a	1.0000	1.0000	1.3333	1.0000	2.6667
Middle of stack	2.3333	1.5000	2.0000 ab	1.0000	1.0000	1.1667	1.0000	2.5000
Back of stack	2.5000	1.5000	1.3333 b	1.0000	1.0000	1.0000	1.3333	2.5000
LSD	2.2031	0.7557	0.7557	0	0	0.4627	0.7557	0.5974
<i>Pr > F</i>	0.9712	0.4444	0.0494	-	-	0.2500	0.4444	0.6944
Container position								
Front of container	2.0000	1.3333	1.6667	1.0000	1.0000	1.0000	1.0000	2.3333 b
Middle of container	2.6667	2.0000	2.1667	1.0000	1.0000	1.1667	1.3333	3.3333 a
Rear of container	2.6667	1.5000	1.8333	1.0000	1.0000	1.3333	1.0000	2.0000 b
LSD	2.2031	0.7557	0.7557	0	0	0.4627	0.7557	0.5974
<i>Pr > F</i>	0.6553	0.1451	0.2844	-	-	0.2500	0.4444	0.0077

^{a-f} “Ratings, as defined in Table 1”.

Table 11: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.1667	2.0000	2.0000 b	1.0000	1.5000	1.1667	1.0000	1.0000
Middle of container	2.3333	2.1667	3.0000 a	1.1667	1.6667	1.1667	1.0000	1.1667
Rear of container	2.5000	2.1667	2.1667 b	1.0000	1.1667	1.3333	1.1667	1.0000
LSD	1.2459	0.4709	0.3333	0.3333	0.9418	0.8156	0.3333	0.3333
<i>Pr > F</i>	0.8130	0.6297	0.0007	0.4219	0.4640	0.8503	0.4219	0.4219

^{a-f} “Ratings, as defined in Table 1”.

Table 12: Effect of FAC to pulp temperatures of – 0.5 °C, 1.5 °C and 3 °C on the quality of ‘Victoria’ grapes packed in perforated carton liners. Values are means and standard errors.

Treatments	Arrival		4 weeks after arrival	
	2005/06	2006/07	2005/06	2006/07
Overall Appearance^a				
- 0.5 °C	2.222 ± 0.177	2.167 ± 0.289	2.674 ± 0.162	2.778 ± 0.192
1.5 °C	2.114 ± 0.193	1.778 ± 0.347	2.633 ± 0.214	2.944 ± 0.152
3 °C	2.348 ± 0.076	2.333 ± 0.373	2.430 ± 0.237	3.555 ± 0.255
Stem Browning^b				
- 0.5 °C	1.256 ± 0.104	1.778 ± 0.192	2.196 ± 0.305	2.389 ± 0.366
1.5 °C	1.322 ± 0.304	1.833 ± 0.373	1.822 ± 0.254	2.333 ± 0.333
3 °C	1.156 ± 0.214	1.611 ± 0.347	1.481 ± 0.118	2.833 ± 0.167
Dry Stems^c				
- 0.5 °C	3.459 ± 0.304	1.667 ± 0.167	4.081 ± 0.134	2.000 ± 0.514
1.5 °C	3.122 ± 0.269	1.444 ± 0.096	4.104 ± 0.058	2.500 ± 0.624
3 °C	2.737 ± 0.566	1.278 ± 0.385	3.752 ± 0.298	3.278 ± 0.304
SO₂ Burn^d				
- 0.5 °C	1.033 ± 0.033	1.000 ± 0.000	1.011 ± 0.019	1.000 ± 0.000
1.5 °C	1.022 ± 0.019	1.056 ± 0.096	1.056 ± 0.038	1.056 ± 0.096
3 °C	1.011 ± 0.019	1.000 ± 0.000	1.011 ± 0.019	1.000 ± 0.000
Decay^e				
- 0.5 °C	1.100 ± 0.667	1.111 ± 0.096	1.056 ± 0.038	1.111 ± 0.152
1.5 °C	1.022 ± 0.030	1.000 ± 0.000	1.011 ± 0.019	1.056 ± 0.096
3 °C	1.070 ± 0.068	1.056 ± 0.096	1.011 ± 0.019	1.167 ± 0.236
Berry Skin Browning^d				
- 0.5 °C	1.237 ± 0.076	1.000 ± 0.000	1.011 ± 0.019	1.167 ± 0.167
1.5 °C	1.233 ± 0.199	1.111 ± 0.192	1.104 ± 0.058	1.333 ± 0.333
3 °C	1.170 ± 0.071	1.889 ± 0.436	1.118 ± 0.101	2.889 ± 0.347
Berry Flesh Browning^d				
- 0.5 °C	1.365 ± 0.247	1.0556 ± 0.096	1.348 ± 0.181	1.111 ± 0.280
1.5 °C	1.133 ± 0.088	1.000 ± 0.000	1.459 ± 0.113	1.222 ± 0.226
3 °C	1.255 ± 0.038	1.000 ± 0.000	1.433 ± 0.220	1.056 ± 0.096
Berry Shatter^f				
- 0.5 °C	1.937 ± 0.098	1.833 ± 0.333	2.678 ± 0.210	2.444 ± 0.304
1.5 °C	1.633 ± 0.208	1.778 ± 0.192	2.033 ± 0.144	2.278 ± 0.385
3 °C	1.914 ± 0.077	1.944 ± 0.096	2.533 ± 0.193	2.111 ± 0.152

^{a-f} “Ratings, as defined in Table 1”.

Table 13: Effect of FAC to pulp temperatures of – 0.5 °C, 1.5 °C and 3 °C on the quality of ‘Regal Seedless’ grapes packed in perforated carton liners. Values are means and standard errors.

Treatments	Arrival		4 weeks after arrival	
	2005/06	2006/07	2005/06	2006/07
Overall Appearance^a				
- 0.5 °C	1.025 ± 0.043	2.278 ± 0.192	-	2.000 ± 0.577
1.5 °C	1.000 ± 0.000	2.111 ± 0.136	-	3.222 ± 0.333
3 °C	1.000 ± 0.000	2.000 ± 0.136	-	3.000 ± 0.215
Stem Browning^b				
- 0.5 °C	2.419 ± 0.133	2.556 ± 0.255	-	3.278 ± 0.319
1.5 °C	1.951 ± 0.229	2.667 ± 0.289	-	2.944 ± 0.096
3 °C	1.642 ± 0.221	2.055 ± 0.272	-	2.667 ± 0.236
Dry Stems^c				
- 0.5 °C	3.481 ± 0.218	2.167 ± 0.167	-	2.889 ± 0.136
1.5 °C	2.914 ± 0.220	2.389 ± 0.430	-	2.833 ± 0.408
3 °C	2.827 ± 0.295	2.056 ± 0.289	-	2.611 ± 0.255
SO₂ Burn^d				
- 0.5 °C	1.000 ± 0.000	1.000 ± 0.000	-	3.000 ± 3.167
1.5 °C	1.000 ± 0.000	1.000 ± 0.000	-	1.056 ± 0.096
3 °C	1.000 ± 0.000	1.000 ± 0.000	-	1.000 ± 0.000
Decay^e				
- 0.5 °C	1.012 ± 0.214	1.111 ± 0.136	-	1.000 ± 0.000
1.5 °C	1.000 ± 0.000	1.278 ± 0.255	-	2.778 ± 0.373
3 °C	1.000 ± 0.000	1.000 ± 0.000	-	1.389 ± 0.272
Berry Skin Browning^d				
- 0.5 °C	1.000 ± 0.000	1.556 ± 0.136	-	3.000 ± 0.518
1.5 °C	1.000 ± 0.000	1.167 ± 0.215	-	1.555 ± 0.518
3 °C	1.000 ± 0.000	1.111 ± 0.096	-	1.111 ± 0.136
Berry Flesh Browning^d				
- 0.5 °C	1.000 ± 0.000	1.056 ± 0.096	-	1.889 ± 0.518
1.5 °C	1.000 ± 0.000	1.056 ± 0.096	-	1.167 ± 0.167
3 °C	1.000 ± 0.000	1.056 ± 0.096	-	1.167 ± 0.000
Berry Shatter^f				
- 0.5 °C	3.543 ± 0.194	1.000 ± 0.000	-	1.000 ± 0.000
1.5 °C	1.963 ± 0.048	1.000 ± 0.000	-	1.611 ± 0.255
3 °C	1.876 ± 0.164	1.222 ± 0.215	-	2.000 ± 0.687

^{a-f} “Ratings, as defined in Table 1”.

Table 14: Effect of FAC to pulp temperatures of – 0.5 °C, 1.5 °C and 3 °C on the quality of ‘Regal Seedless’ grapes packed in non-perforated liners during 2006/2007 season. Values are means and standard errors.

Treatments	Arrival	4 weeks after arrival
Overall Appearance^a		
- 0.5 °C	2.111 ± 0.192	2.333 ± 0.360
1.5 °C	1.944 ± 0.215	2.667 ± 0.544
3 °C	1.889 ± 0.255	3.167 ± 0.136
Stem Browning^b		
- 0.5 °C	2.000 ± 0.000	2.111 ± 0.136
1.5 °C	1.944 ± 0.962	2.333 ± 0.272
3 °C	1.556 ± 0.255	2.444 ± 0.272
Dry Stems^c		
- 0.5 °C	2.000 ± 0.000	2.389 ± 0.096
1.5 °C	1.944 ± 0.962	2.389 ± 0.319
3 °C	1.833 ± 0.167	2.722 ± 0.585
SO₂ Burn^d		
- 0.5 °C	1.000 ± 0.000	1.056 ± 0.096
1.5 °C	1.000 ± 0.000	1.000 ± 0.000
3 °C	1.000 ± 0.000	1.000 ± 0.000
Decay^e		
- 0.5 °C	1.000 ± 0.000	1.444 ± 0.272
1.5 °C	1.056 ± 0.096	1.944 ± 0.553
3 °C	1.000 ± 0.000	1.000 ± 0.000
Berry Skin Browning^d		
- 0.5 °C	1.222 ± 0.167	1.222 ± 0.236
1.5 °C	1.056 ± 0.096	1.167 ± 0.136
3 °C	1.111 ± 0.000	1.456 ± 0.385
Berry Flesh Browning^d		
- 0.5 °C	1.111 ± 0.136	1.056 ± 0.096
1.5 °C	1.056 ± 0.096	1.167 ± 0.215
3 °C	1.000 ± 0.000	1.000 ± 0.000
Berry Shatter^f		
- 0.5 °C	1.000 ± 0.000	1.056 ± 0.096
1.5 °C	1.000 ± 0.000	1.444 ± 0.609
3 °C	1.333 ± 0.333	2.000 ± 0.373

^{a-f} “Ratings, as defined in Table 1”.

Table 15: Effect of FAC to pulp temperatures of – 0.5 °C, 1.5 °C and 3 °C on the quality of ‘Victoria’ grapes packed in non-perforated liners during the 2006/2007 season. Values are means and standard errors.

Treatments	Arrival	4 weeks after arrival
Overall Appearance^a		
- 0.5 °C	2.055 ± 0.152	2.500 ± 0.236
1.5 °C	1.167 ± 0.167	2.444 ± 0.561
3 °C	2.389 ± 0.255	3.167 ± 0.118
Stem Browning^b		
- 0.5 °C	1.833 ± 0.167	1.722 ± 0.255
1.5 °C	1.222 ± 0.192	1.611 ± 0.192
3 °C	1.778 ± 0.304	2.444 ± 0.281
Dry Stems^c		
- 0.5 °C	1.056 ± 0.096	1.667 ± 0.471
1.5 °C	1.000 ± 0.000	1.889 ± 0.192
3 °C	1.444 ± 0.280	2.722 ± 0.536
SO₂ Burn^d		
- 0.5 °C	1.000 ± 0.000	1.000 ± 0.000
1.5 °C	1.000 ± 0.000	1.000 ± 0.000
3 °C	1.000 ± 0.000	1.000 ± 0.000
Decay^e		
- 0.5 °C	1.056 ± 0.096	1.111 ± 0.192
1.5 °C	1.000 ± 0.000	1.000 ± 0.000
3 °C	1.000 ± 0.000	1.000 ± 0.000
Berry Skin Browning^d		
- 0.5 °C	1.056 ± 0.096	1.111 ± 0.152
1.5 °C	1.056 ± 0.096	1.167 ± 0.118
3 °C	1.944 ± 0.226	1.944 ± 0.347
Berry Flesh Browning^d		
- 0.5 °C	1.056 ± 0.096	1.111 ± 0.152
1.5 °C	1.000 ± 0.000	1.111 ± 0.192
3 °C	1.000 ± 0.000	1.000 ± 0.000
Berry Shatter^f		
- 0.5 °C	1.555 ± 0.255	2.722 ± 0.436
1.5 °C	1.500 ± 0.236	2.556 ± 0.152
3 °C	2.111 ± 0.226	2.000 ± 0.441

^{a-f} “Ratings, as defined in Table 1”.

Table 16: A comparison between the Thermocouple and Thermocron iButton pulp temperature readings at the termination of pre-cooling (FAC).

A. TUNNEL 1 – Target pulp temperature of $-0.5\text{ }^{\circ}\text{C}$

Pallet	Thermocouple readings	Thermocron iButton reading
1	-0.50	0.35
2	-0.20	0.61
3	-0.20	0.73
4	-0.90	0.70
5	-0.60	0.97
6	-0.80	1.03
7	-0.80	1.00
8	-0.50	0.79
9	-0.10	1.00
Average	-0.51	0.80

B. TUNNEL 2 – Target pulp temperature of $1.5\text{ }^{\circ}\text{C}$

Pallet	Thermocouple readings	Thermocron iButton reading
10	0.90	2.67
11	0.90	3.24
12	0.90	2.45
13	0.90	3.31
14	0.40	2.60
15	0.70	3.70
16	1.60	3.57
17	1.60	2.81
18	4.20	3.79
Average	1.34	3.13

C. TUNNEL 3 – Target pulp temperature of $3\text{ }^{\circ}\text{C}$

Pallet	Thermocouple readings	Thermocron iButton reading
19	3.40	4.97
20	3.40	4.40
21	1.90	4.54
22	3.60	5.00
23	2.50	4.90
24	1.70	4.04
25	3.20	5.76
26	3.60	3.75
27	3.00	3.89
Average	2.92	4.58

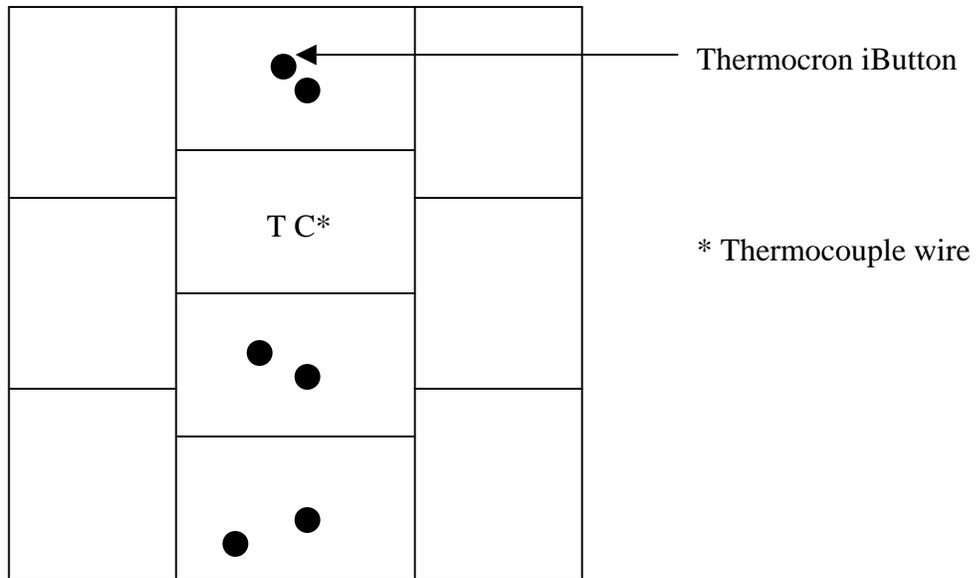


Figure 1: Schematic presentation of a top view of a pallet layer of 4.5 kg cartons and positioning of Thermocron iButtons in a layer.

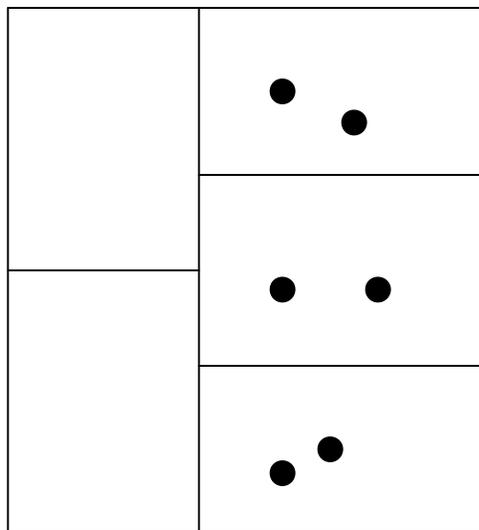


Figure 2: Schematic presentation of a top view of a pallet layer of punnet cartons and positioning of Thermocron iButtons in a layer.

**ARTICLE II: TEMPERATURE DISTRIBUTION IN A PRE-COOLING
STACK AND IN-TRANSIT REEFER CONTAINERS LOADED
WITH TABLE GRAPES**

ABSTRACT

To deliver horticultural products in a desirable, fresh and saleable condition to the distant markets, good cold chain management is required. Temperature was monitored in different positions (front, middle and rear) and in different layers (top, middle and bottom) in both the pre-cooling stacks and 40' reefer containers. Although there were no significant differences in the different positions and layers of the pre-cooling stack, a trend was observed where the pallets placed in the front position of the stack (near the fans) ended up with the lowest temperature compared to the middle and rear positions. The rear position in reefer containers resulted in significantly higher ($P = 0.00000$) pulp temperatures, while the front position (near cooling unit) resulted in the lowest pulp temperatures. The difference in pulp temperature between the layers in the reefer container was not significant. However, a trend was observed where the bottom layers ended up with the lowest pulp temperature followed by the middle layer and the top layer had higher pulp temperature.

Keywords: Temperature, airflow, convection, refrigeration, table grapes, reefer container, pre-cooling stack.

INTRODUCTION

Good temperature management is crucially important in the fruit export industry to ensure a supply of good quality fruits to distant markets. Pre-cooling is likely the most important operation followed by a good cold chain management that ensures maintenance of desirable, fresh and saleable condition of produce (Arin *et al.*, 2004; Brosnan *et al.*, 2001; Nelson, 1979 and Mitchell, 1987).

In the majority of food refrigeration systems, convection is the primary mode of heat transfer, therefore the air distribution system must provide sufficient airflow to absorb the energy from the heat sources such as walls, doors and often the product itself to avoid unacceptable temperature increases (Smale *et al.*, 2006). The single most important requirement for uniform produce temperatures is uniform cooling over the entire area on the top of the stack (Wills *et al.*, 1989). As reviewed by Smale *et al.* (2006), recent studies have shown a significant level of spatial temperature variability in some food refrigeration systems, with non uniform airflow implicated as a major cause of this variability. Ideally there should be a continuous, narrow, air slot in the direction of airflow past at least two faces of every box or carton and each side of every bulk bin, with no large vertical gaps in the stack to allow short-circuiting by the cool air (Wills *et al.*, 1989). In research done by Tanner and Amos (2003), they found some variation in temperature distribution of kiwi fruits along the length of a 40' reefer container. They found that the temperature range during a steady state period in the container was from 5 to 6 °C, with the door end having the maximum temperature.

Table grapes are pre-cooled to a statutory temperature of -0.5 °C in South Africa, but despite the efforts of reducing temperatures to such low levels, there are still some quality problems that arise during transport to distant markets. The objective of the study was to monitor temperatures in various positions in a pre-cooling stack and 40' reefer containers, as well as in various layers within pallets. The temperatures were monitored through the entire cold chain in order to identify potential problem areas that need attention in the cold chain to ensure good temperature management.

MATERIALS AND METHODS

Plant material and origin: The trials were conducted in consecutive seasons (2005/06 and 2006/07) in the Lower Orange River and Hex River areas, covering early, dryer and late, wetter production zones, respectively. In the Orange River the grapes ('Victoria') were sourced and packed at AAA Trust and pre-cooled at Augpad cooling facilities. In

Hex River the grapes ('Regal Seedless') were sourced and packed at Wolwehoek Trust and pre-cooled at Hexkoel.

Packaging and cooling: The grapes were commercially ripe (14 °Brix- 'Victoria' and 18 °Brix – 'Regal Seedless'). 'Victoria' grapes were packed in commercial 4.5 kg cartons that were lined with 2 mm perforated liners. The grape bunches were packed in polycote bags and were covered with commercially used Uvays SO₂ pads to control *Botrytis cinerea*. 'Regal Seedless' grapes were packed in commercial 5 kg cartons that were lined with 4 mm perforated liners. The grape bunches were packed in punnets and were covered with a commercially used Uvays SO₂ pads to control *Botrytis cinerea*. The pulp temperature during pre-cooling was monitored with thermocouple wires until the target pulp temperature was reached. However, Thermocron® iButton® (DS1921Z-F5) temperature loggers (supplied by Dallas Semiconductor, iButton Product Group, Dallas, Texas) were used to measure the temperature throughout the cold chain, i.e. from pre-cooling through to the European market and they were retrieved on arrival in Rotterdam.

Placement of Thermocron buttons for temperature measurement: To measure the pulp temperature extra large 'Red Globe' berries were cut in half in a longitudinal section with a sharp knife, then the vascular tissue with a bit of pulp was removed carefully to create room for the placement of the button inside the berries. Once each button was carefully placed inside the berries, the two halves of the berries were replaced back into position, enclosing the 'Thermocron' button inside the berry. A rubber band was used to seal the two halves of the berry together. The 'Red Globe' berries were use for easy identification amongst the white berries. The berries with the buttons were placed in between the berries of bunches in the polycote bag ('Victoria') and in punnets ('Regal Seedless') inside the cartons. To measure the air temperature inside the cartons the 'Thermocron' button was attached on the outside of the polycote bag ('Victoria') with a strip of adhesive tape, while for 'Regal Seedless' the buttons were loosely placed in the punnets. Temperatures were recorded in the 4th, 10th and 16th layers from the pallet base, in three cartons per layer of each experimental pallet. There were two buttons in each of the three cartons per layer, one in the 'Red Globe' berry to measure pulp temperature and the other

one was hung with an adhesive tape to measure air temperature in the carton. The buttons were distributed in each layer as per figures 13 and 14.

Positioning of experimental pallets in the pre-cooling tunnels and in reefer containers:

Three pre-cooling tunnels were used and in each pre-cooling tunnel there were 20 pallets of which 9 were experimental pallets. When the grapes reached the target pulp temperature in each tunnel, all 20 pallets were loaded into a 40' reefer container ready to be transported to the port for shipping. In each pre-cooling tunnel, three experimental pallets (out of nine) were placed in the front position (coolest position, near the fan), three were placed in the middle position and three were placed at the rear position (warmest position) of the pre-cooling stacks. Likewise in the reefer containers, three pallets were placed in front (coolest position, near cooling unit), three in the middle and three at the back of the container (warmest position, near the doors). One pallet from each of the three tunnel positions was placed in the front, middle and back of each 40' reefer container. Therefore, all permutations of coolest-, intermediate- and warmest tunnel positions with coolest-, intermediate- and warmest reefer container positions were covered. The reefer containers were set at a delivery air temperature (DAT) of $-0.5\text{ }^{\circ}\text{C}$ and were transported under generator power to the port.

A Sensitech Temptale 3 data recorder was used to measure the relative humidity in the reefer containers. The delivery air temperature was measured by placing the Thermocron buttons in every second floor channel from the left to the right side of the container. The pallets were packed in reefer containers in a 9/11 configuration and the gap near the door was blocked off by the use of cardboard, which was cut to fit the gap and stapled on the pallet base to block off the forklift openings.

Statistics:

A Statistica program, version 7, was used to analyse the temperature data. The procedure that was used was repetitive measures. The tunnels' temperature data were analysed separately from the reefer container data. The 'Thermocron' buttons were recording data

at 30 minutes intervals, throughout the cold chain, but for the purpose of the analyses, daily mean temperatures were calculated and used to get the analyses of variance (ANOVA). The temperature distribution along the height (between pallet layers) and along the length (between the different positions) of both the tunnels and reefer containers were compared.

RESULTS

Pre-cooling tunnels: Within the pre-cooling stacks there were no significant differences in the pulp temperatures of the grapes between the different positions and different layers in the stack (Figures 1, 2, 3 and 4). However, there were trends that were observed. In all the pre-cooling stacks, the front position (near the fans) resulted in the fastest cooling (Figures 2 and 4). The cooling trends between the different layers of the stack, showed fastest cooling of the top layer and slowest cooling in the bottom layer (Figures 1 and 3).

40' reefer containers: The pulp temperatures of the 'Victoria' and 'Regal Seedless' grapes that were placed at the rear position in reefer containers were significantly higher ($P = 0.00000$) than pulp temperature of the grapes placed in the front and middle positions (Figures 5, 7 and 9). Although the pulp temperatures of the grapes placed in the front and middle positions in the reefer container did not differ significantly, the trends show that the front position consistently resulted in lower pulp temperatures, followed by the middle position (Figures 5, 7 and 9). The grapes loaded into the reefer container at 3°C , cooled down to the same pulp temperature as the grapes loaded at -0.5°C within a week of shipping (Figures 6 and 7). This was true for the front and the middle positions in the container, while the back position remained constantly high. The trends showed that the bottom layers of the pallets resulted in the lowest pulp temperatures, followed by the middle layers and the top layers resulted in higher temperatures (Figures 6, 8 and 10). The results (Figures 11 and 12) show a tendency of temperature variation of DAT across the width of each reefer container between the floor channels.

DISCUSSION

The trends that were observed between the different positions in the pre-cooling stacks may be due to a greater pressure gradient of cold air through the pallets near the fans than further away from the fans. However, these differences in pulp temperatures were not statistically significant, suggesting that the design and management of the pre-cooling stack was very good.

The temperature distribution patterns that were observed in this trial confirm the results obtained by Tanner and Amos (2003). The temperature differences between the front and rear in the 40' reefer container in this trial were not as great as found in their research, as the temperature difference in this trial was only as high as 1.23 °C. The front resulted in colder grape pulp temperatures than the middle and the rear positions in both reefer containers. This trend was observed despite the fact that the floor was completely sealed to avoid short-circuiting of the cold air. From an aerodynamic perspective, the key characteristic of transport equipment is the placement of the delivery air and return air units on the same face (Smale *et al.*, 2006). However, the drawback of this asymmetrical design is the presence of a strong pathway between the two sections, implying high velocities in the front of the refrigerated enclosure. In addition, the compactness of the cargo and high resistance to airflow due to narrow air spaces between pallets result in an uneven air distribution in the cargo where stagnant zones with poor ventilation can be observed in the rear part of the vehicle (Smale *et al.*, 2006). Moureh *et al.* (2002 and 2004) used different models to show the airflow distribution in both the loaded and unloaded refrigerated truck. Their models showed high air velocities in the front of the refrigerated truck configuration compared to the rear parts. Fastest cooling is obtained when the floor is completely covered with product (Thompson *et al.*, 1998).

The reefer containers used in this trial had bottom-delivery airflow and refrigerated air is supplied to the product through a floor plenum. The trends that were observed between the different layers in the cargo can be ascribed to the vertical distribution of the cold air from the bottom up. Hence, the bottom layers showed the lowest pulp temperatures

followed by the middle layer then the top layer in both the reefer containers. The inner packaging materials must therefore allow vertical airflow for adequate cooling between the layers (Thompson *et al.*, 1998).

The difference in patterns of the spatial variation of DAT across the width of containers one (Figure 11) and two (Figure 12) may be due to an incorrect vent setting in container 2. The pattern seen in the DAT of container two is typical of a container with an open vent, based on the work done by Tanner and Amos (2003), while the pattern seen in container one (1) falls out of the scope of this research as the container had a closed vent. These variations can be ascribed to the technical limitations e.g. the design of the reefer containers. Tanner and Amos (2003) ascribed the variation in DAT (same pattern as Figure 12) to the reduced airflow on the right side of the container evaporator from differential coil frosting as this side corresponded to the positioning of the fresh air vent. When the containers (vessel) were on route in the ocean, the increased moisture load of the ambient air was released onto the coil primarily on the right side. This would have increased the airflow resistance on this side of the container resulting in a higher delivery temperature (Tanner and Amos, 2003). When there is an ice formation on the coils due to moisture load, the warm return air passing over the coils is prevented from being cooled down (Thompson *et al.*, 1998), resulting in a higher delivered air temperature.

CONCLUSION

The results obtained in this trial showed that there are some temperature variations from the pre-cooling stage through to the end of the cold chain. These variations are ascribed to inadequate cold air distribution through the horticultural products. There is very little that can be done to improve the situation by standard management practices e.g. sealing all the openings in the stacks and in the reefer containers. It is therefore likely that the problems of airflow are mainly due to technical limitations of the equipment, i.e. reefer container design. More attention needs to be given to the design and engineering side of the refrigerated transport equipment over and above ensuring a proper packaging, ventilation and stuffing of the cooling stacks and reefer containers. The implication of the

results suggests that the reefer containers have a capacity to cool the grapes further, when loaded at 3°C. The horizontal cooling system may improve this cooling, while reducing the differences between the front and the rear of the container (M. Dodd, personal communication). The differences in temperatures seen in this trial strongly emphasise the importance of managing the cold chain properly, since there is no room for more mistakes in the cold chain management as this might add up to the loss of produce quality.

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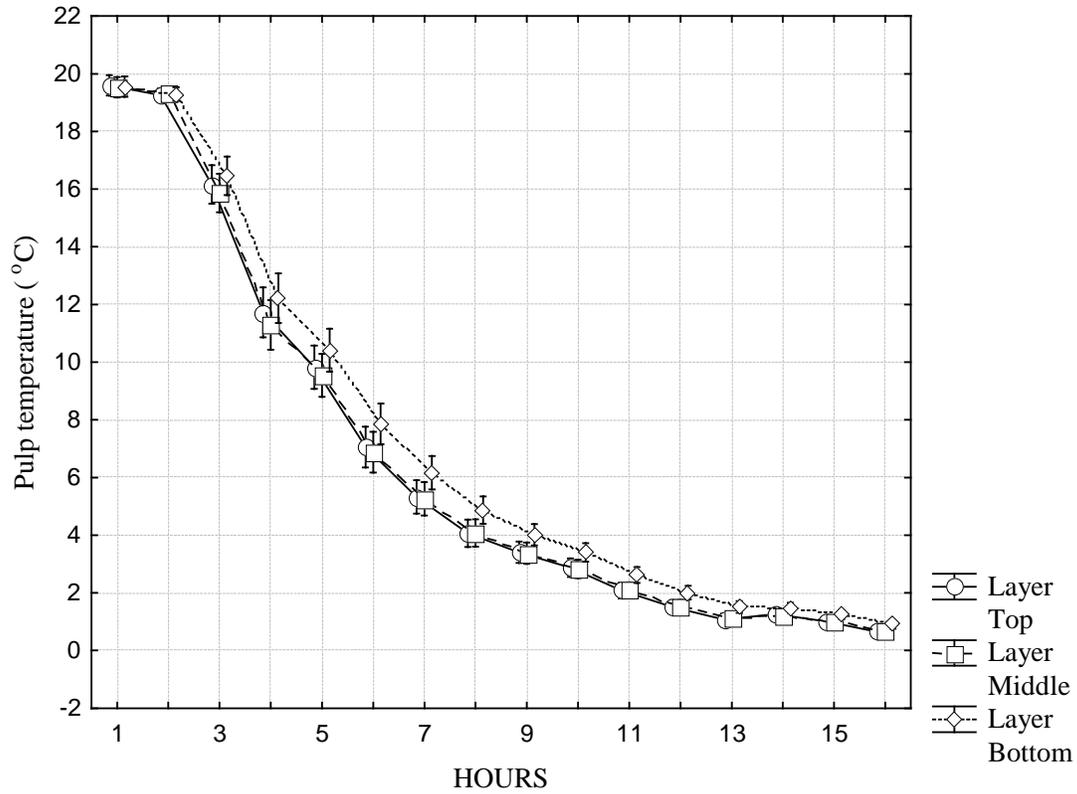


Figure 1: The rate of ‘Victoria’ pulp temperature cooling in the different pallet layers of the pre-cooling tunnel at Augpad cooling facilities (pre-cooling tunnel 1).

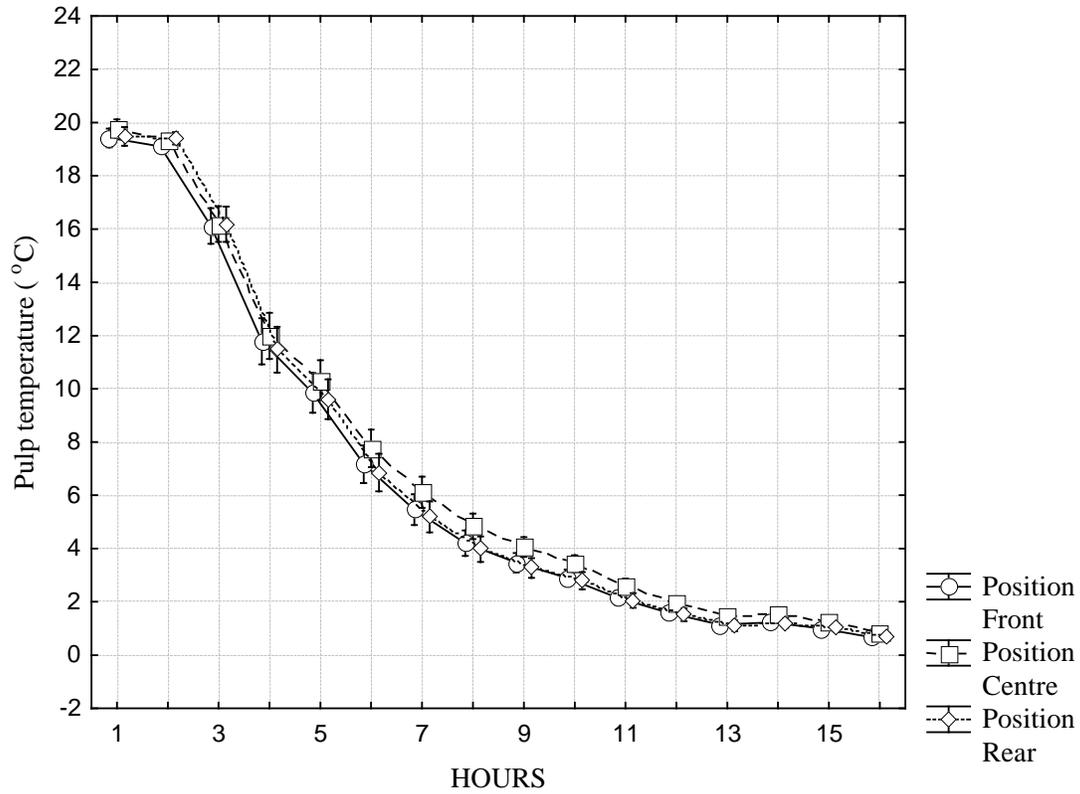


Figure 2: The rate of ‘Victoria’ pulp temperature cooling in the different pre-cooling pallet positions at Augpad cooling facilities (pre-cooling tunnel 1).

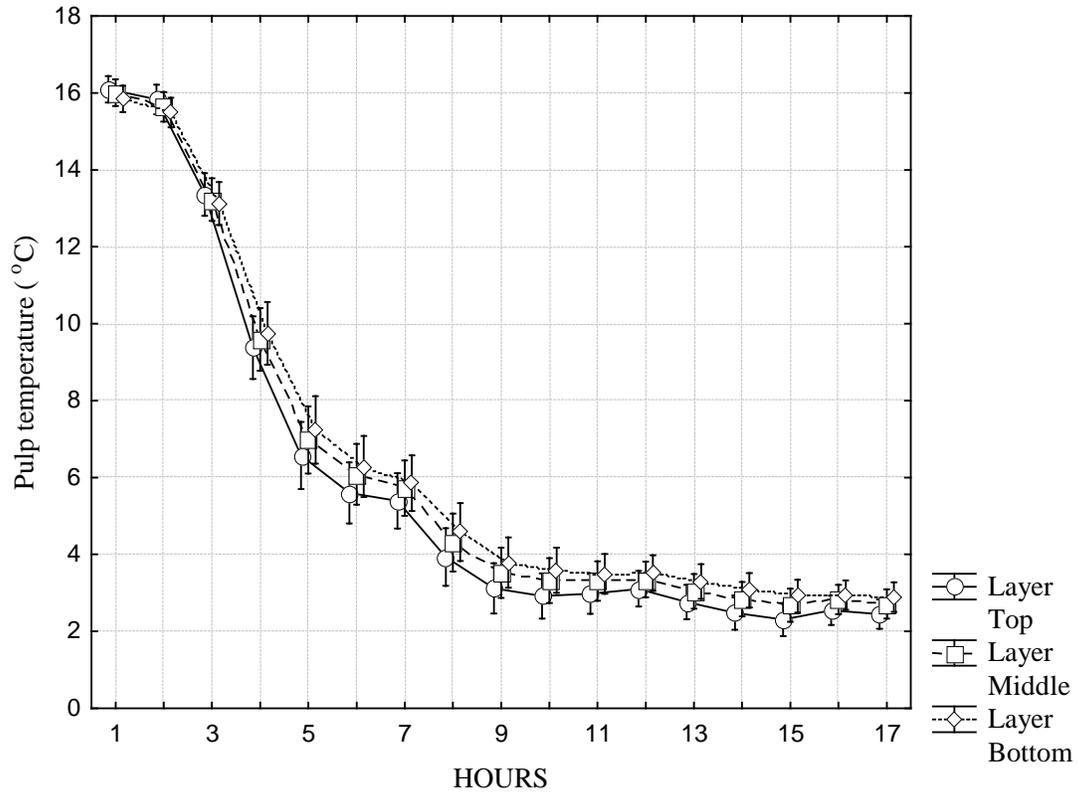


Figure 3: The rate of ‘Victoria’ pulp temperature cooling in the different pallet layers of the pre-cooling tunnel at Augpad cooling facilities (pre-cooling tunnel 2).

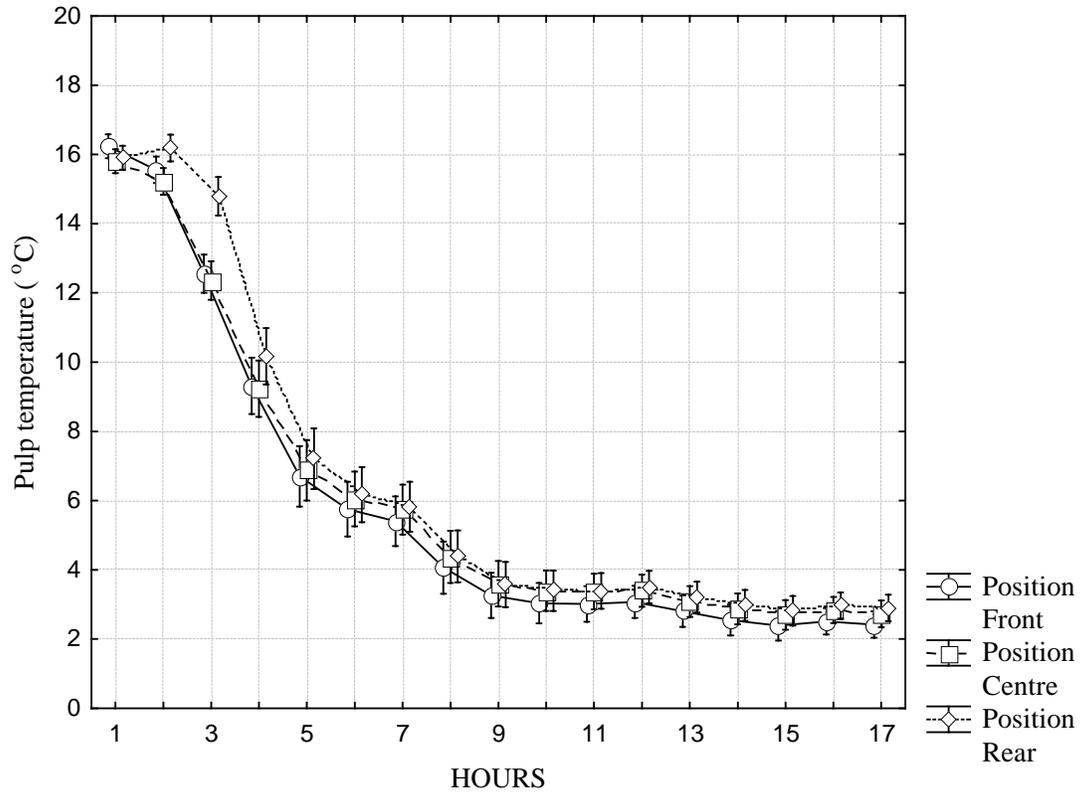


Figure 4: The rate of ‘Victoria’ pulp temperature cooling in the different pre-cooling Pallet positions at Augpad cooling facilities (pre-cooling tunnel 2).

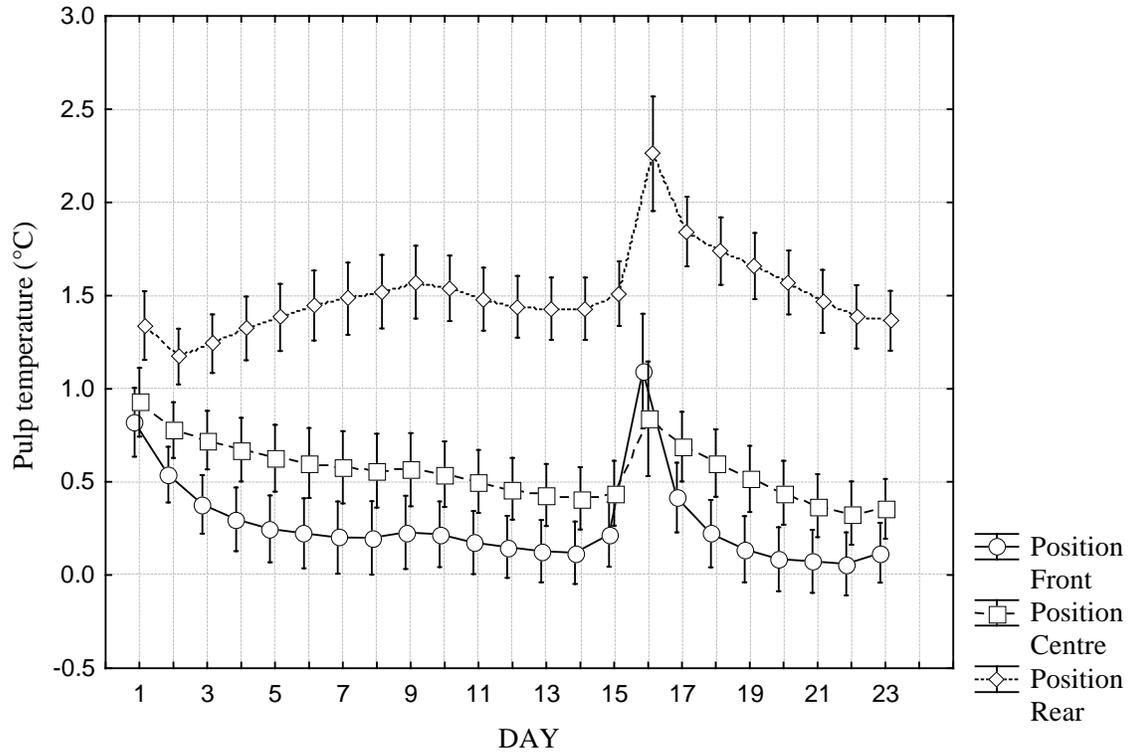


Figure 5: 'Victoria' grape pulp temperature distribution in a 40' reefer container 1 from front (near cooling unit) to rear (near the doors).

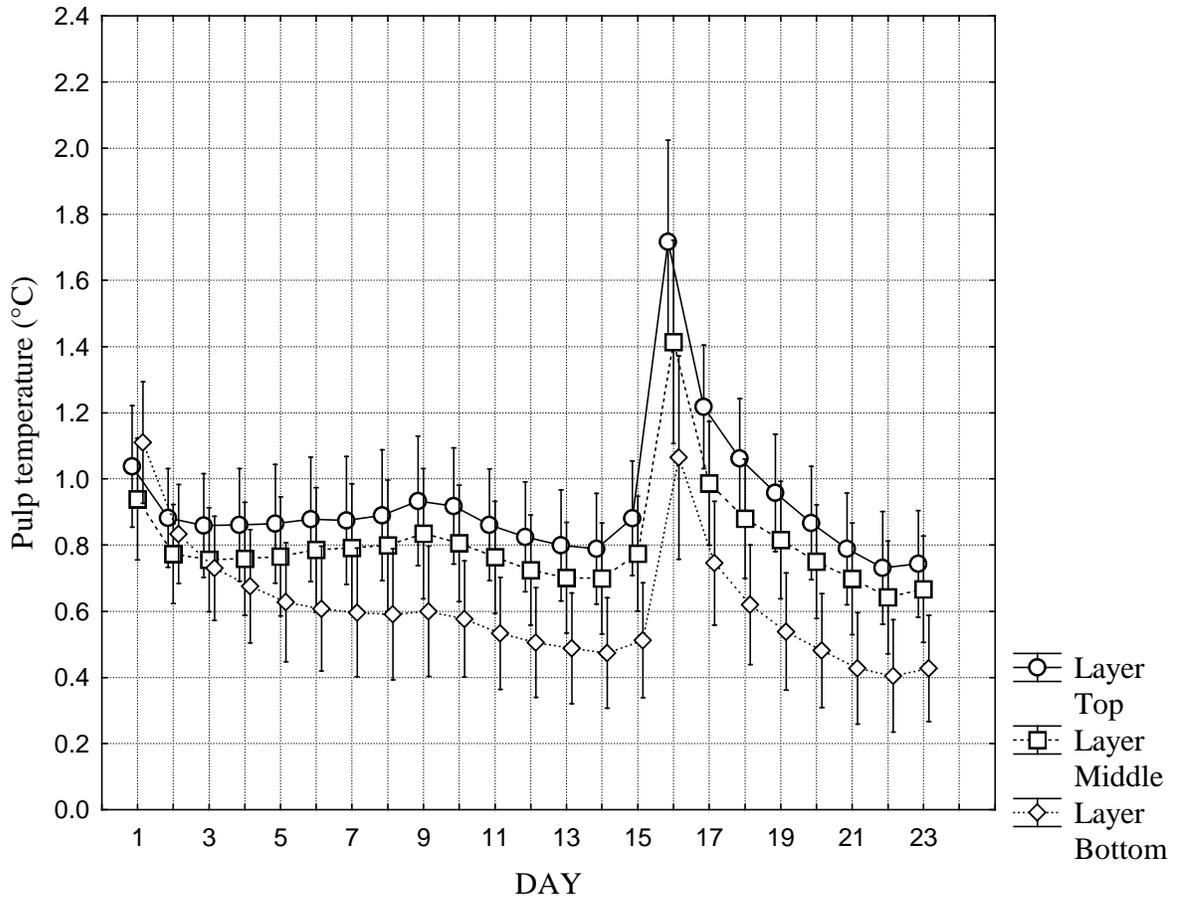


Figure 6: 'Victoria' grape pulp temperature distribution in a 40' reefer container 1 from the bottom pallet layers to the top layers.

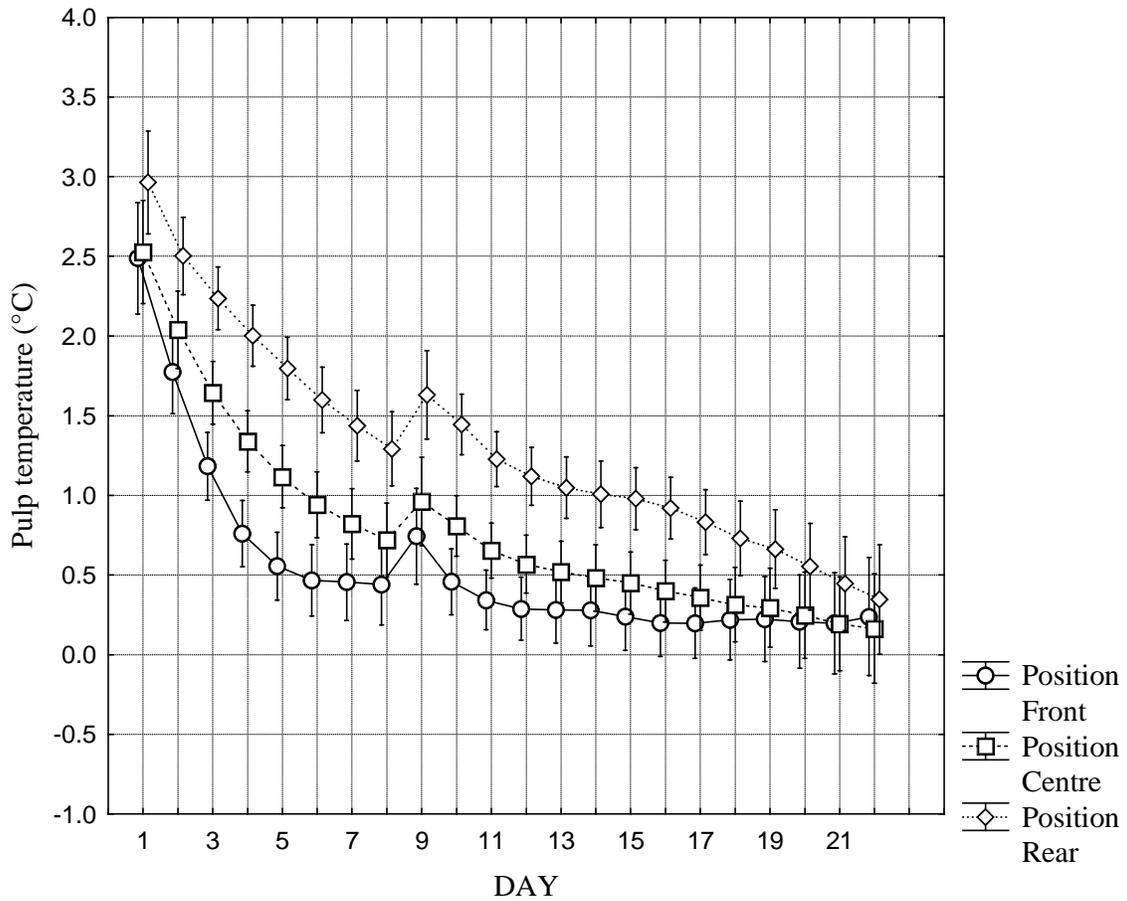


Figure 7: 'Victoria' grape pulp temperature distribution in a 40' reefer container 2 from front (near cooling unit) to rear (near the doors).

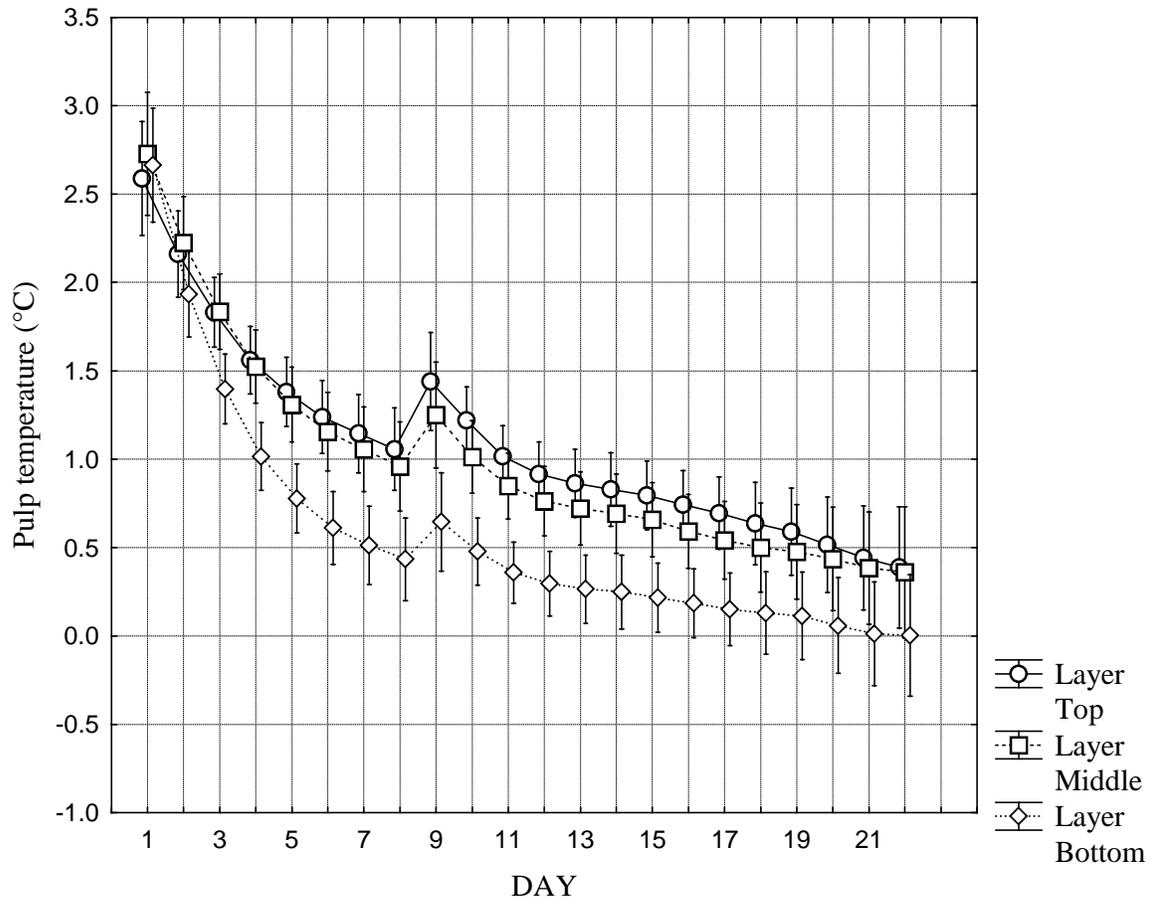


Figure 8: 'Victoria' grape pulp temperature distribution in a 40' reefer container 2 from the bottom pallet layers to the top layers.

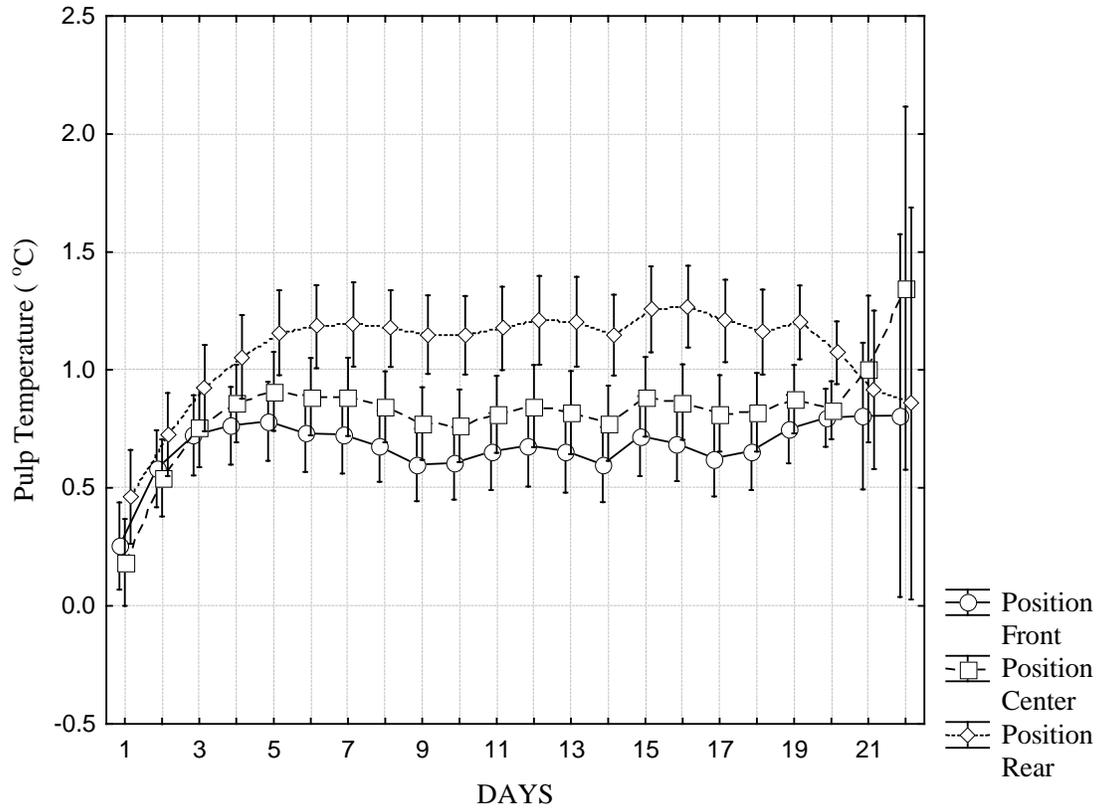


Figure 9: 'Regal Seedless' grape pulp temperature distribution in a 40' reefer container from front (near cooling unit) to rear (near the doors).

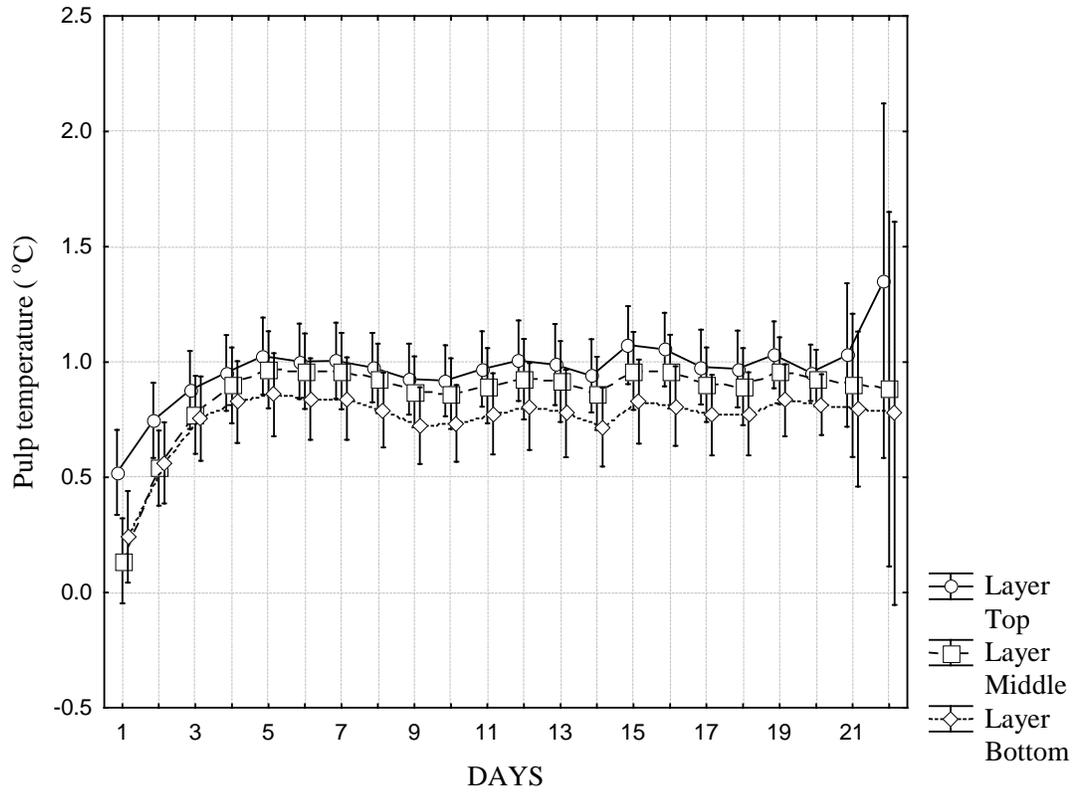


Figure 10: 'Regal Seedless' grape pulp temperature distribution in a 40' reefer container from the bottom pallet layers to the top layers.

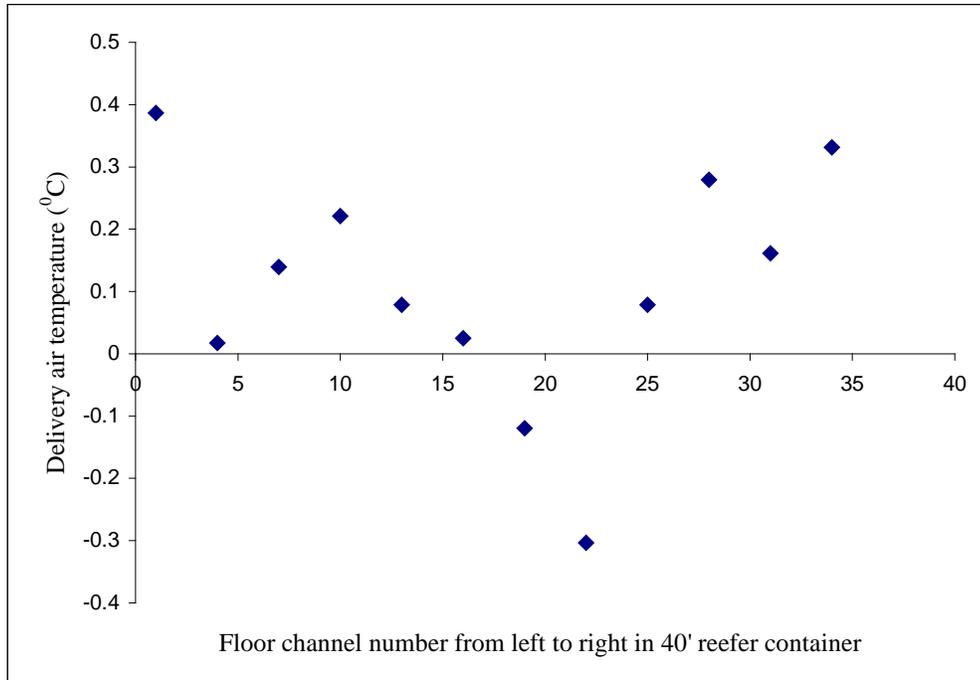


Figure 11: Average delivery air temperature in the floor channel of a reefer container 1, set at a DAT of $-0.5\text{ }^{\circ}\text{C}$, during shipping from Cape Town (FPT) harbour through to Rotterdam (Seabrix) harbour.

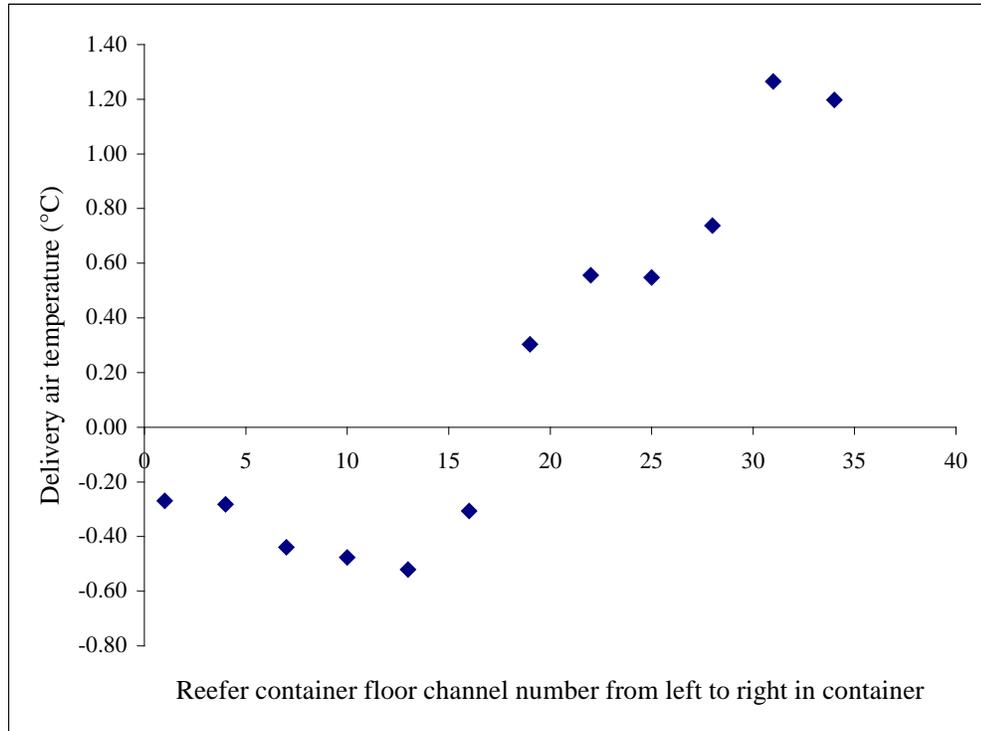


Figure 12: Average delivery air temperature in the floor channel of a reefer container 2, set at a DAT of $-0.5\text{ }^{\circ}\text{C}$, during shipping from Cape Town (FPT) harbour through to Rotterdam (Seabrix) harbour.

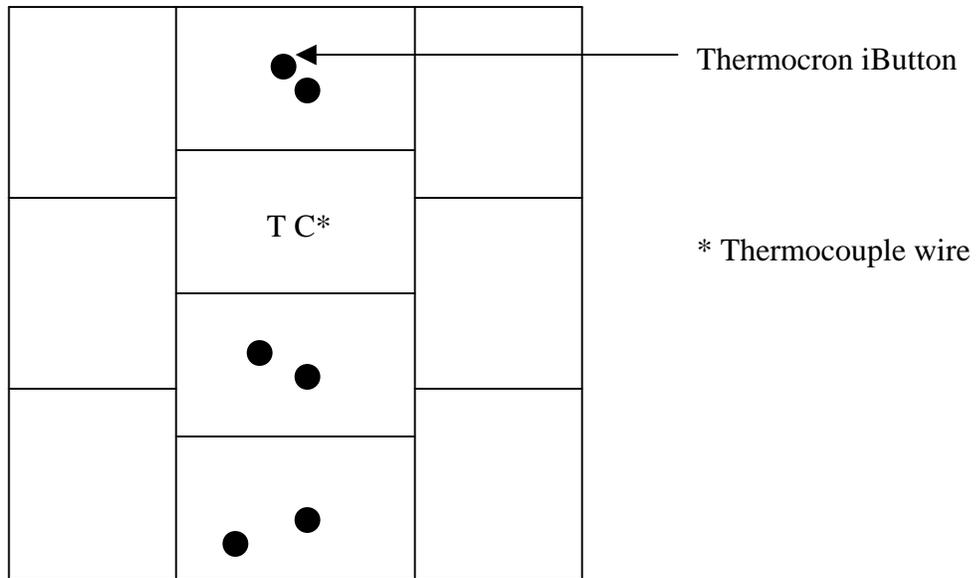


Figure 13: Schematic presentation of a top view of a pallet layer of 4.5 kg cartons and positioning of Thermocron iButtons in a layer.

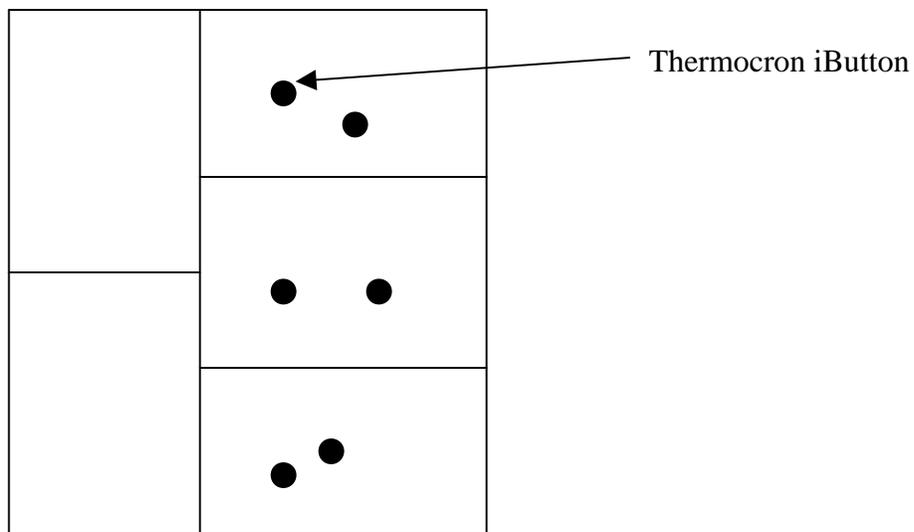


Figure 14: Schematic presentation of a top view of a pallet layer of punnet cartons and positioning of Thermocron iButtons in a layer.

ARTICLE III: THE EFFECT OF FORCED AIR COOLING ENDPOINT TEMPERATURES ON THE STABILITY OF TABLE GRAPE BERRY MEMBRANES

ABSTRACT:

The effect of forced air cooling (FAC) of table grapes ('Victoria' and 'Regal Seedless') to a statutory pulp temperature of $-0.5\text{ }^{\circ}\text{C}$ on the berry membranes was investigated in comparison to forced air cooling to higher pulp temperatures of $1.5\text{ }^{\circ}\text{C}$ and $3\text{ }^{\circ}\text{C}$ and static, room cooling to $-0.5\text{ }^{\circ}\text{C}$ (control). Forced air cooling to a pulp temperature of $3\text{ }^{\circ}\text{C}$ resulted in a significant decrease ($P = 0.00000$) in electrolyte leakage from both the skin and the pulp after 4 weeks of storage at $-0.5\text{ }^{\circ}\text{C}$. In 'Victoria', the control showed an increase in the percentage of electrolyte leakage from the skin tissue from week 0 to week 4 of storage, while the control for the pulp tissue showed a significant increase of the percentage leakage from week 0 to week 2, which was followed by a significant decrease in week 4. In 'Regal Seedless', the control for both the skin and the pulp tissue showed a significant increase in the percentage leakage from week 0 to week 2, which was followed by a significant decrease in week 4. The FAC to $1.5\text{ }^{\circ}\text{C}$ resulted in a slight increase in electrolyte leakage from the Victoria skin tissue from week 0 to week 2, which was followed by a significant decrease in week 4, while the pulp tissue showed a significant decrease from week 0 to week 2, followed by a significant increase in week 4. In 'Regal Seedless', FAC to $1.5\text{ }^{\circ}\text{C}$ resulted in a significant increase in electrolyte leakage from week 0 to week 4 in the skin tissue, while the pulp tissue showed a decrease from week 0 to week 2 followed by an increase in week 4. The FAC to $-0.5\text{ }^{\circ}\text{C}$ showed a significant decrease in percentage electrolyte leakage from week 0 to week 4 from the skin tissue of 'Victoria', while the pulp tissue showed an increase from week 0 to week 2, which was followed by a significant decrease in week 4. In 'Regal Seedless' the FAC to $-0.5\text{ }^{\circ}\text{C}$ resulted in a significant decrease in electrolyte leakage from week 0 to week 2, which was followed by a significant increase in week 4 from the skin tissue. The opposite was true in the pulp tissue, where there was a significant increase in the electrolyte leakage from week 0 to week 2, followed by a significant decrease in week 4.

Keywords: Forced air cooling (FAC), chilling injury (CI), membrane permeability, electrolyte leakage, cold acclimation.

INTRODUCTION:

Membranes are dynamic structures that support numerous biochemical reactions and they are also major targets of environmental stresses (Campos *et al.*, 2003). Chilling and freezing are the major consequences of low temperature stress in plants (Shewfelt, 1992). Chilling injury (CI) is a physiological disorder induced by low, non-freezing temperatures that affects both plants and fruit from tropical and subtropical origins (Sanchez-Ballesta *et al.*, 2006). There are many symptoms of chilling injury to horticultural crops associated with the changes in membrane permeability (Murata, 1990). These include pitting, sheet pitting, shrivelling, wilting, scald, surface lesions, water soaking of tissues, internal discolouration (browning), breakdown of tissues, failure of fruits to ripen in the expected pattern, accelerated rate of senescence, increased susceptibility to decay, shortened storage, compositional changes related to consumer acceptance, and loss of normal growth capacity (Murata, 1990; Bramlage *et al.*, 1990). Among these symptoms, pitting, sheet pitting, shrivelling and wilting may be considered as a result of increased permeability of vapour from the cells to the ambient atmosphere. There may be changes in membrane permeability of phenol substances in the course of browning of tissue (Murata, 1990). Cellular changes that are often used as indicators of the severity of chilling injury include changes in the membrane structure and composition, cessation of protoplasmic streaming, and plasmolysis of cells and an increased rate of leakage from the cells occurring in a variety of tissues (Saltveit *et al.*, 1990).

Membrane permeability is an expression of the freedom with which water and solutes can pass through the membrane (Murata, 1990). Methods for measurement of membrane permeability in intact crops have not been completely established. Therefore, in most cases, membranes in the excised tissues, callus, or isolated organelles have to be used for

the measurement of permeability. Permeability can be assessed by the rate of leakage of solutes, including ions, amino acids, sugars, and pigments, from the tissues to the medium (Murata, 1990). Increased rates of solute and electrolyte leakage occur in a variety of chilled tissues (Campos *et al.*, 2003) and have been widely used by many researchers to evaluate membrane damage following chilling (Campos *et al.*, 2003; Lurie *et al.*, 1987; Wright and Simon, 1973).

The main reason for cooling and storing horticultural products at low temperatures is to reduce the loss of their pre-harvest quality after harvest, until they are consumed in the distant markets. As product temperature increases, the rate of biological reactions (e.g. respiration) increases logarithmically (Kays *et al.*, 2004). For every 10 °C rise in temperature, the rate of respiration is roughly doubled or tripled (Hardenburg *et al.*, 1986), this increase in rate follows van't Hoff's rule. This makes cooling alone the most important step in the entire value chain. It is apparent from van't Hoff's rule that for every 10°C drop in product temperature (through cooling) from higher temperatures, there is a doubled to a tripled advantage in terms of fruit quality. However, the gained advantage in terms of quality in cooling diminishes (gets smaller and smaller) as the product temperature decreases. Reducing a product temperature from 5 °C to 0 °C, takes longer than an equivalent reduction in temperature from 20 °C to 15 °C as the product temperature approaches the temperature of the cooling medium. Lyons (1973) states that exposure to chilling temperatures must be relatively long before cells of most sensitive plants are injured. In general, the severity of injury of sensitive plant tissues increases as temperature is lowered or as exposure is extended at any chilling temperature (Lyons, 1973).

South African table grapes are forced air cooled to a statutory pulp temperature of –0.5°C before they can be shipped to the distant markets. Most white table grape cultivars exhibit the postharvest disorder of browning. The cause of this browning disorder in table grapes is not really known. There has been a perception in the industry that forced air cooling might be the cause of browning of table grapes. This perception might have arisen from the fact that in many fruits (e.g. stone fruits), tissue browning has been

associated with chilling injury. This research was then designed to investigate whether pre-cooling table grapes to a pulp temperature of $-0.5\text{ }^{\circ}\text{C}$ was not damaging (causing chilling injury) to the membranes and thus conducive to browning (discolouration).

MATERIALS AND METHODS

Plant material and packaging: ‘Regal Seedless’ table grapes were sourced from Appiesklip, in Worcester, and ‘Victoria’ grapes were sourced from Eureka in Paarl. The grapes were commercially ripe ($15\text{ }^{\circ}\text{Brix}$ - ‘Victoria’ and $18.5\text{ }^{\circ}\text{Brix}$ – ‘Regal Seedless’) and were packed in commercial 4.5 kg cartons that were lined with 2 mm perforated liners. The grape bunches were packed in polycote bags and were covered with commercially used Uvays SO_2 pads to control *Botrytis cinerea*. The pulp temperature was monitored with thermocouple wires.

FAC treatments and sampling: The grapes were forced-air cooled to target pulp temperatures of $-0.5\text{ }^{\circ}\text{C}$, $1.5\text{ }^{\circ}\text{C}$ and $3\text{ }^{\circ}\text{C}$ using a portable forced air cooler in the Horticultural Science department at the University of Stellenbosch. The electrolyte leakage measurements from each treatment were done immediately following FAC (time 0) and following 2 and 4 weeks of storage at $-0.5\text{ }^{\circ}\text{C}$. The control was cooled by means of static room cooling, but the berries were sampled at the same time as the other treatments. Therefore, the pulp temperature of the control was not necessarily the same as the pulp temperature of the grapes from the different FAC treatments *per se*. This was done because it was thought that timing might add (through senescence) to the difference between the electrolyte leakage from the control and that of the FAC treatments. All the grapes used in this trial were put under cooling at the same time following packing in the packhouse.

Pulp electrolyte leakage: Disc cylinders were cut from individual berries with a 6 mm cork borer, and the ends of each grape pulp cylinder were cut with a sharp blade to remove the skin. Each cylinder was halved tangentially to remove the seeds (‘Victoria’) or seed traces (‘Regal Seedless’) and vascular tissue around the seeds. There were six

replications from each treatment and each replicate was made up of a 2 g tissue sample. Samples were rinsed 3 times in de-ionised water and carefully dried with a paper towel before incubation in 25 ml of 0.4 M mannitol solution at ambient temperature (~ 25 °C) for 4 hours. The Orion Aplus™ basic conductivity meter was calibrated with the conductivity/TDS standard 1413uS, (692 ppm NaCl) solution, prior to measurement of electrolyte leakage. The discs were removed from the incubation solution prior to measurement. During measurement a magnetic stirrer was used to ensure homogeneity of the solution. Once measurement was completed, the sample discs were placed back into the incubation solution and were subsequently boiled at 100 °C (using a hot plate) for about 8 minutes to ensure that all membranes were broken for total leakage. After boiling, the samples were quickly cooled down to ambient temperature by placing the beaker in cold water prior to measurement. The percentage leakage of each sample was calculated by dividing the initial leakage by the total leakage and expressed as a percentage.

Skin electrolyte leakage: the skins from the different treatments were carefully peeled from the berries ensuring that there was very little pulp attached to the skin. Any pulp was carefully removed using the blunt side of the knife. There were six replications per treatment and each replicate was made up of a 2 g skin tissue sample. The same steps that were carried out for the pulp were also repeated for the skin to obtain the percentage leakage from the skin.

Statistical analyses

Statistica version 7 program was used to determine the analyses of variance (ANOVA) and LS means within 95 % confidence intervals. A two-way analyses of variance procedure was used to analyse the data set.

RESULTS

‘Victoria’

Skin leakage (Fig 1): The control showed a significant increase in leakage from 35.1 % (week 0) to 39.4 % (week 2), which was followed by a further significant increase to 42.7 % in week 4. The FAC to 3 °C resulted in a significant decrease of electrolyte leakage from 57.6 % (week 0) to 31.7 % (week 2) and then the leakage stayed stable at 31.2 % in week 4. FAC to 1.5 °C resulted in a fairly stable electrolyte leakage in the first two weeks, which was followed by a significant decrease to 41.8 % in week 4. The FAC to – 0.5 °C resulted in a decrease in electrolyte leakage from 44.7 % (week 0) to 42.1 % (week 2), which was followed by a further decrease to 39.6 % in week 4. FAC to 3 °C resulted in the highest initial leakage, but the lowest leakage following storage. Contrary to all the FAC treatments, in which leakage decreased over time, the control berries showed increased leakage during storage.

Pulp leakage (Fig 2): The control showed a significant increase in electrolyte leakage from 65.2 % (week 0) to 70.3 % (week 2), which was followed by a significant decrease to 62.9 % in week 4. The forced air cooling to pulp temperature of 3 °C resulted in a significant decrease in electrolyte leakage from 82.1 % (week 0) to 72.8 % (week 2) followed by a further significant decrease to 65.2 % (week 4). FAC to 1.5 °C did not follow the same trend as the other treatments and the control. The observations from this treatment showed a significant decrease in the percentage of electrolyte leakage from 88.3 % (week 0) to 75.7 % (week 2), followed by a significant increase from week 2 to 84.7 % in week 4. Forced air cooling grapes to a pulp temperature of – 0.5 °C resulted in a steady electrolyte leakage in the first two weeks, followed by a significant decrease from week 2 to 71.9 % (week 4). Although there was a significant decrease in electrolyte leakage after 4 weeks of storage in most of the treatments, the control ended with the lowest percentage leakage out of the pulp in week 4, followed by the FAC to 3 °C treatment and then FAC to – 0.5 °. The difference between the control and FAC to 3 °C was not significant after 4 weeks of storage.

‘Regal Seedless’

Skin leakage (Fig 3): The control showed a slight, non-significant decrease in the percentage of electrolyte that leaked out from the skin from 46.6 % (week 0) to 44.4 % (week 2), followed by a significant increase from week 2 to 51.6 % in week 4. FAC to 3 °C showed a stable leakage from 51.3 % (week 0) to 51.2 % (week 2), followed by a significant decrease in percentage leakage to 42.7 % in week 4. FAC to 1.5 °C resulted in a slight, non-significant increase in electrolyte leakage from 47.3 % (week 0) to 48.9 % (week 2), followed by a significant increase of electrolyte leakage up to 55.6 % in week 4. FAC to –0.5 °C resulted in a significant decrease in electrolyte leakage from 47.3 % (week 0) to 43.1 % (week 2), followed by a significant increase in electrolyte leakage to 54.9 % in week 4.

Pulp leakage (Fig 4): The control showed a significant decrease in electrolyte leakage from 80.3 % (week 0) to 71.0 % (week 2), followed by a significant increase to 75.0 % in week 4. FAC to 3 °C showed a significant decrease in electrolyte leakage from 78.4 % (week 0) to 69.3 % (week 2) followed by a further significant decrease to 65.6 % in week 4. FAC to 1.5 °C resulted in a significant decrease in electrolyte leakage from 78.9 % (week 0) to 70.9 % (week 2), followed by a significant increase to 78.3 % in week 4. FAC to – 0.5 °C resulted in a significant increase in electrolyte leakage from 72.6 % (week 0) to 80.4 % (week 2), followed by a significant decrease to 66.0 % in week 4.

In both ‘Victoria’ and ‘Regal Seedless’ grapes, there were generally large differences between the percentage electrolyte leakage from the skin and pulp tissue (Tables 1 and 2).

DISCUSSION

Based on the results observed in this research, forced air cooling ‘Victoria’ and ‘Regal Seedless’ table grapes to a pulp temperature of 3 °C resulted in a reduced amount of electrolytes that leaked out of the membranes in storage at a temperature of –0.5 °C. This may have been due to membrane adaptation to lower temperatures (cold acclimation) of

the grapes that were pre-cooled to a pulp temperature of 3 °C. Cold acclimation is a process by which certain plant species decrease their susceptibility to low temperature stress during a modification of environmental conditions (Shewfelt, 1992; Wang, 1993). The two most intensively studied aspects of cold acclimation are cold-hardening of grains to reduce freezing injury and conditioning of harvested fruits and vegetables to reduce postharvest chilling injury (Shewfelt, 1992). The fluidity of the membrane bilayer is determined, to a large extent, by the fatty acid composition of the phospholipids (Wang, 1993). The flexibility of the membranes is associated with the relative proportion of saturated and unsaturated fatty acids in membrane glycerol lipids (Wang, 1993). Temperature conditioning has been reported to increase the degree of unsaturation of fatty acids in phospholipids (Wang, 1993). Experimental evidence suggests that desaturases, which adds double bonds to the fatty acids, are very selective in the molecular species they modify. The greatest potential for such retailoring to alter membrane phase properties is offered by the high-melting molecular species of PG in thylakoids and glucocerebrosides in plasma membrane (Shewfelt, 1992). The increase in fatty acid unsaturation by temperature conditioning has been proposed to be a result of altered fatty acid desaturase activity, and not preferential biosynthesis of individual phospholipids (Wang, 1993). Lurie *et al.* (1987) found that electrolyte leakage from apple discs decrease from 21.5% (at harvest) to 19.5% after 2 weeks of storage at 0°C and this remained constant throughout the storage period of 24 weeks. They stated that the membranes underwent adaptation to storage conditions, which resulted in a decrease in permeability. The temperature conditioning also suppresses the increase of the sterol/phospholipid ratio during chilling (Wang, 1993). This ratio is closely associated with membrane viscosity and permeability (Wang, 1993). It also affects the fluidity of membranes and, in turn, influences the capacity of tissue to withstand chilling stress (Wang, 1993). Treatments that suppress the increase in the free sterol/phospholipid ratio tend to reduce chilling injury (Wang, 1993). Evidence has been accumulating that suggests that lipid peroxidation contributes to the development of chilling injury, and temperature conditioning may reduce chilling injury by protecting membrane lipids from peroxidation (Wang, 1993).

Other treatments gave varied results between the two cultivars. 'Victoria' decreased leakage while 'Regal Seedless' showed an increase in electrolyte leakage in week 4. The increase is thought to be due to the membrane phase changes. The membrane phase change hypothesis (Lyons, 1973), states that at a certain critical temperature within the chilling injury range the membrane lipids of chill-sensitive plants undergo a transition from a liquid-crystalline to solid gel state (Wilson *et al.*, 1981). Membranes that depend on fluidity begin to solidify at sub-optimal temperatures, which severely disrupt the function of membrane-associated proteins (reviewed by Basra, 2001) and the change in state would be expected to bring about a contraction that causes cracks or channels, leading to increased permeability (Lyons, 1973). It is thought that the two main consequences of this transition, which eventually result in injury and death, are an increase in membrane permeability and an increase in the activation energy of membrane bound enzymes (Wilson *et al.*, 1981). Whilst an increase in activation energy in itself may not be damaging to a plant, it is thought that lethal increases in ethanol and acetaldehyde content may occur due to a metabolic imbalance between non-membrane bound glycolytic reactions and membrane bound enzymes of the tricarboxylic acid cycle (Wilson *et al.*, 1981).

The role of lipids in the prevention of low temperature injury is suggested by increases observed in the degree of unsaturation and often weight of lipid per cell during the acclimatization of plants as well as ectothermic and endothermic animals to low temperatures (reviewed by Wilson *et al.*, 1981). It was thought that an increase in the degree of unsaturation of the membrane fatty acids of 5 to 12 % prevented chilling injury by lowering the phase transition temperature to below 5 °C (Wilson *et al.*, 1981).

There are very few reports on work that has been done on membrane permeability of the exocarp (skin) cells. This is probably due to the difficulty involved in the peeling of the skin tissue of fruits. Most of the work that was done on membrane permeability involves the pulp (flesh) tissue. Hence, there has never been a comparison between the response of the skin and the pulp tissue to chilling temperatures. The results obtained in this trial showed large differences in the percentage of electrolyte leakage between the skin and

the pulp tissue. There was a generally low electrolyte leakage from the skin tissue compared to the pulp tissue. This was true for both 'Victoria' and 'Regal Seedless' grapes. This difference may have resulted from the toughness of the skin cell, due to natural waxes and cuticle material on these cells. The skin of a grape berry comprises an outer 1-cell deep epidermis and an inner 4-20-cell deep hypodermis (Bamforth, 2005). Wilson and Sterling (1976) did some studies on the cuticle of tomato fruit. They stated that cuticle of tomato fruit was covered by a very thin layer of epicuticular wax. They also stated that the total cuticular domain is composed of a cutinised layer just above the secondary wall of the epidermal cell consisting of several strata and a cuticle outside this layer. The cuticular domain covering the epidermal cells may be the reason for the large differences between the skin and the pulp leakage.

CONCLUSION

Apart from the FAC to 3 °C treatment, which resulted in the same trends of electrolyte leakage, it seems as if 'Victoria' and Regal Seedless' react differently towards the forced air cooling treatments. Although the FAC to 3 °C resulted in a decreased electrolyte leakage in week 4 of storage at -0.5 °C, the initial leakage at week 0 (when a pulp temperature of 3 °C is reached) was high. Further research is needed to investigate aspects of the handling chain that result in membrane damage. Chilling injury is a result of cumulative temperature abuses within the cold chain. The symptoms of chilling injury are usually only visible when the grapes are already in the market, and this makes it difficult to pin point where exactly in the cold chain temperatures were poorly managed.

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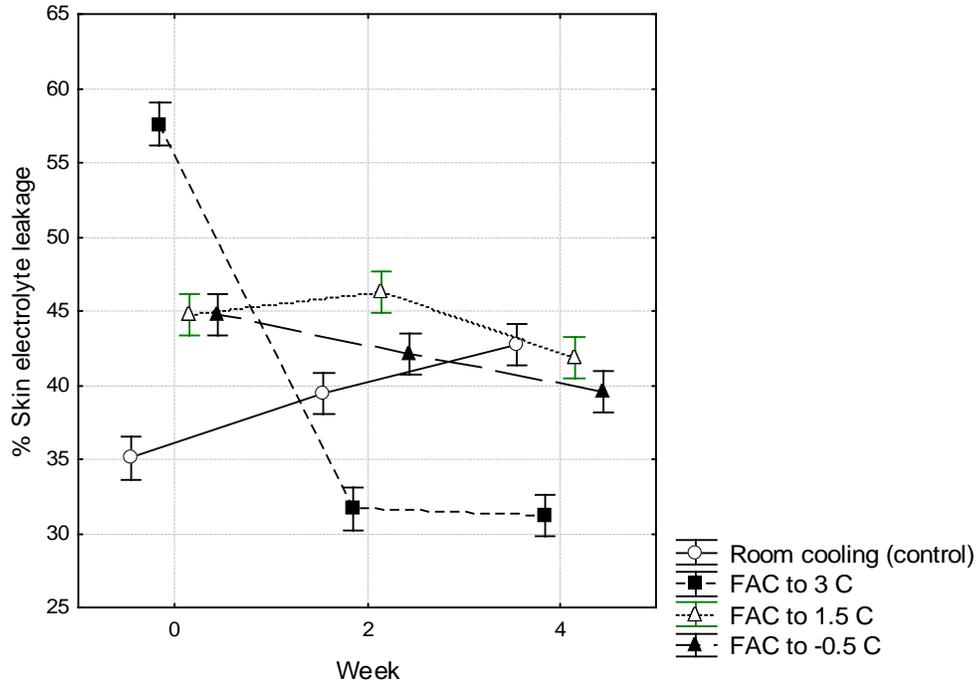


Figure 1: Electrolyte leakage (%) from Victoria grape skin after being exposed to FAC treatments (week 0) and after 2 and 4 weeks of storage at -0.5°C .

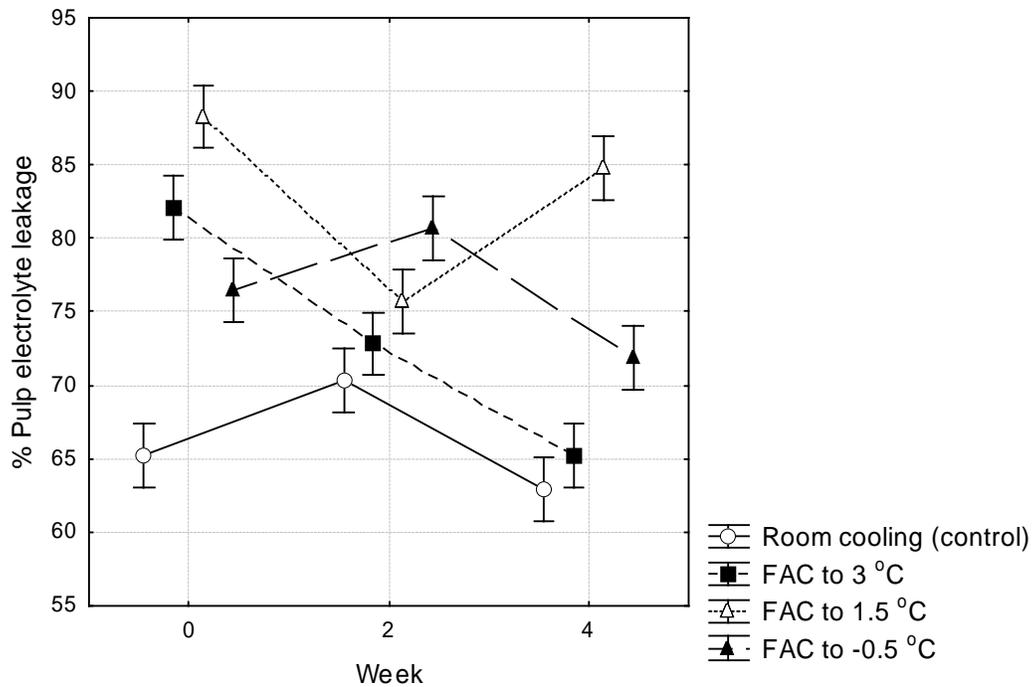


Figure 2: Electrolyte leakage (%) from Victoria grape pulp after being exposed to FAC treatments (week 0) and after 2 and 4 weeks of storage at -0.5°C .

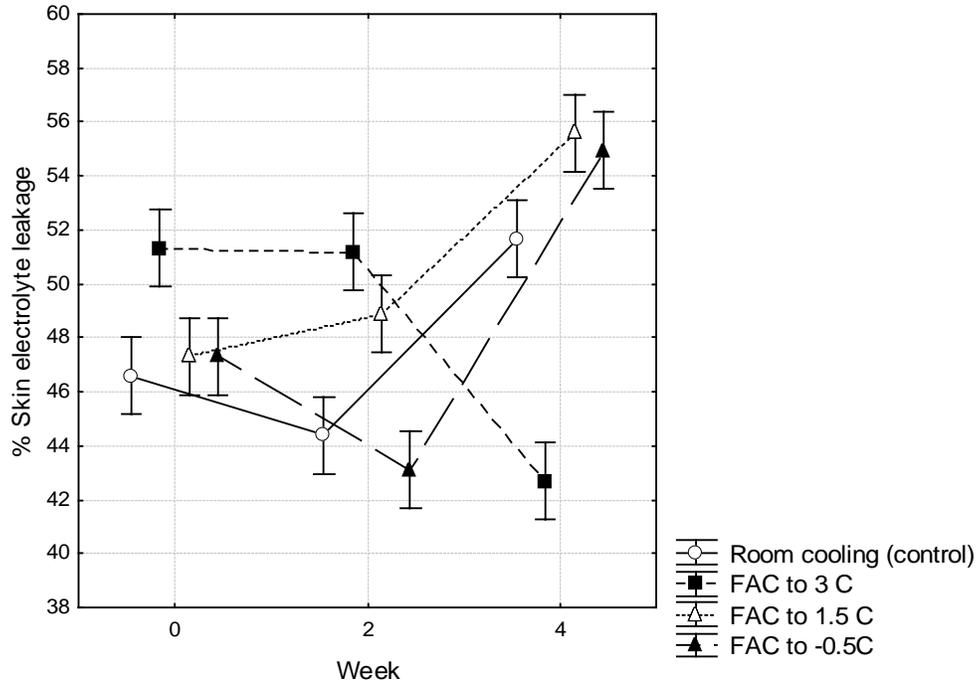


Figure 3: Electrolyte leakage (%) from Regal seedless grape skin after being exposed to FAC treatments (week 0) and after 2 and 4 weeks of storage at -0.5°C .

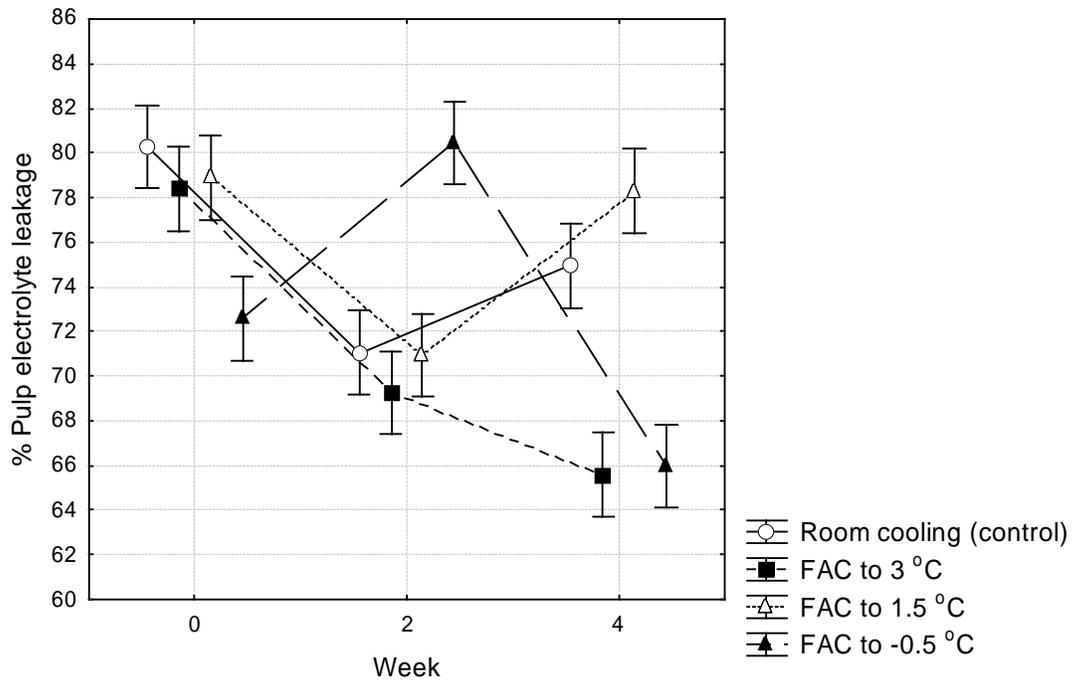


Figure 4: Electrolyte leakage (%) from Regal seedless grape pulp after being exposed to FAC treatments (week 0) and after 2 and 4 weeks of storage at -0.5°C .

Table 1: Comparisons of Means and Standard errors of electrolyte leakage (%) from the skin and pulp tissue of 'Victoria' grape berries after FAC (week 0) and storage at $-0.5\text{ }^{\circ}\text{C}$ (week 2 and week 4).

Sampling period	% Skin leakage	% Pulp leakage
Week 0	45.53	78.03
Week 2	39.85	74.89
Week 4	38.84	71.19
Standard Error	± 0.707	± 1.078

Table 2: Comparisons of Mean and Standard errors of electrolyte leakage (%) from the skin and pulp tissue of 'Regal Seedless' grape berries after FAC (week 0) and storage at $-0.5\text{ }^{\circ}\text{C}$ (week 2 and week 4).

Sampling period	% Skin leakage	% Pulp leakage
Week 0	48.13	77.54
Week 2	46.88	72.93
Week 4	51.22	71.21
Standard Error	± 0.714	± 0.939

Tables 1 and 2 show pooled data for all treatments in each sampling week.

GENERAL DISCUSSION AND CONCLUSION

Proper cooling and maintenance of the cold chain are important in ensuring that good quality fruits are delivered to the distant markets. Nelson (1978) states that table grapes should be cooled promptly and thoroughly immediately after harvest to minimize water loss from the fruit, to retard development of decay caused by fungi, and to reduce the rate of respiration. Despite all the efforts of managing the cold chain, South African table grapes develop some quality problems such as dry and brown stems and berry browning (white varieties) upon arrival in the distant markets.

The effects of cooling to pulp temperatures of 1.5°C and 3°C in comparison to the current statutory pulp temperature of -0.5°C and the positioning in the pre-cooling tunnels and reefer containers on quality of table grapes were studied. Also the temperature distribution in both the pre-cooling stacks and loaded reefer containers, as well as the effect of forced air cooling on table grape membranes were studied.

Both 'Victoria' and 'Regal Seedless showed better quality when FAC to 1.5 °C and 3 °C in comparison to FAC to -0.5 °C. There were no economic losses associated with pre-cooling the grapes to pulp temperatures of 1.5 °C and 3 °C in comparison to those cooled to the statutory pulp temperature of -0.5 °C. In most tunnels and reefer containers, positioning showed no significant differences. However, in cases where there were significant differences in the measured variables, the middle and the rear positions generally showed better quality of table grapes than the front position in both the pre-cooling stack and in the reefer containers. The main differences were observed in the stem condition, where warmer positions resulted in less drying and browning of stems compared to the cooler positions. This indicates that the warmer positions tended to result in better fruit quality. In table grapes brown and dry stems are evidence of water loss (Nelson, 1978). Both Thompson *et al.* (1998) and Nelson (1978) state that fruit water loss is due to the vapour pressure deficit (Vpd), which is the evaporative potential of the surrounding environment where the fruits are kept.

$$Vpd = \frac{Vp \times 100 - RH}{100}$$

Where Vpd = vapour pressure deficit (mm of Hg); Vp = vapour pressure (mm of Hg) and RH = relative humidity (%).

It is apparent from the above equation that the Vpd increases as the Vp increases (which would occur with a rise of temperature) (Nelson, 1978). Furthermore, the Vpd will increase as the RH is lowered. The results were a bit contradictory with the above equation, but the poor stem conditions (dry and brown stems) in the front positions (near cooling units – coolest area) may have been due to air turbulences rather than the temperature differences. Smale *et al.* (2006) researched airflow distribution using various models and found that there is variation in air distribution in refrigerated rooms and transport vehicles (Smale *et al.*, 2006). This variation was due to air turbulence near the cooling units. The turbulence may be removing the humidity from the fruit surroundings, thus creating some vapour pressure deficit on the surface of the fruit and promoting moisture loss from the fruit.

There were no significant differences in pulp temperatures of grapes between the different positions in the pre-cooling tunnels, suggesting that the design and management of the pre-cooling stack was very good. However, the trends show the front position (near fans) to be cooler than the back positions. This may be due to a greater suction force of cold air through the pallets near the fans than further away from the fans. The temperature gradient in the reefer containers confirmed the results obtained by Tanner and Amos (2003). The front position (near cooling units) was significantly cooler than the rear position in all reefer containers. The mean delivery air temperatures measured in the floor channels from left to right in the reefer containers, suggested that the left side (as one looks from the doors into the container) was cooler than the right side. Tanner and Amos (2003) pointed out that this difference in the DAT was due to the ice formation on the coil on the right hand side. They state that there are vents on the right side on the containers near the coil, and water vapour from the humid air condenses on the coil, forming ice if the coil temperature is below 0 °C (as is commonly the case with shipments

of table grapes). This in turn prevents proper cooling of the return air and thus the air delivered on the right side is not properly cooled.

Based on the results observed in this research, forced air cooling 'Victoria' and 'Regal Seedless' table grapes to a pulp temperature of 3 °C resulted in a reduced amount of electrolytes that leaked out of the membranes in storage at a temperature of -0.5 °C. However, there was no berry browning that could be associated with the effect of FAC on the grape membranes (as determined by the percentage electrolyte leakage). There were also large differences between the percentage electrolyte leakage between the skin tissue and the pulp tissue. The skin tissue had less leakage than the pulp tissue, and this was ascribed to the cuticles, waxes and lignification on the skin cells (Bamforth, 2005; Wilson and Sterling, 1976).

Cooling table grapes to higher pulp temperatures of 1.5°C or 2°C might be beneficial to reduce cooling time and increase the throughput of the cold rooms. Proper management of the cold chain can never be overemphasised in order to reduce the problems such as moisture loss and decay on the grapes. There was no clear evidence to suggest that berry browning was due to FAC treatments.

Further research is needed to try and better understand the cause of berry browning, because if the causes are known then preventative measures can be taken. Future studies must include pre-harvest factors that induce browning such as microclimates of the orchards, canopy cover, as well as handling from harvest to packing in the pack house.

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APPENDIX A: SELECTED DATA OF ARTICLE I

- Table 1: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of 'Victoria' table grapes that were pre-cooled to -0.5°C (2005/06 season).
- Table 2: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 1.5°C (2005/06 season).
- Table 3: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 3°C (2005/06 season).
- Table 4: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 1.5°C (2005/06 season).
- Table 5: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 3°C (2005/06 season).
- Table 6: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of 'Victoria' table grapes that were pre-cooled to 3°C (2006/07 season).
- Table 7: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to -0.5°C (2006/07 season).
- Table 8: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 1.5°C (2006/07 season).
- Table 9: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of 'Victoria' table grapes that were pre-cooled to -0.5°C (2006/07 season).
- Table 10: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of 'Victoria' table grapes that were pre-cooled to 1.5°C (2006/07 season).
- Table 11: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to -0.5°C (2006/07 season).

- Table 12: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 3 °C (2006/07 season).
- Table 13: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to -0.5 °C (2006/07 season).
- Table 14: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).
- Table 15: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 3 °C (2006/07 season).
- Table 16: Effect of position in the reefer container on the quality (4 weeks after arrival) of 'Regal Seedless' table grapes that were pre-cooled to -0.5 °C (2006/07 season).
- Table 17: Effect of position in the reefer container on the quality (4 weeks after arrival) of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).
- Table 18: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to -0.5 °C (2006/07 season).
- Table 19: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).
- Table 20: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 3 °C (2006/07 season).
- Table 21: Effect of position in the reefer container on the quality (4 weeks after arrival) of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).
- Table 22: Effect of position in the reefer container on the quality (4 weeks after arrival) of 'Regal Seedless' table grapes that were pre-cooled to 3 °C (2006/07 season).

Figure 1: Picture showing stem browning in 'Regal Seedless' table grapes.

Figure 2: Picture showing berry flesh browning in 'Victoria' table grapes.

Table 1: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to – 0.5°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.3667	1.2667	3.7767	1.00000	1.06667	1.1000	1.3100	2.0333
Middle of stack	2.2000	1.4000	3.2667	1.10000	1.23333	1.4433	1.3433	1.9667
Back of stack	2.1000	1.1000	3.3333	1.00000	1.00000	1.1667	1.4433	1.8100
LSD	0.6967	0.4104	1.1929	0.1309	0.2618	0.2979	0.9695	0.3845
Pr > F	0.6026	0.2417	0.4985	0.1600	0.1451	0.0664	0.9255	0.3520
Container position								
Front of container	2.3000	1.3667	3.6667	1.03333	1.03333	1.2000	1.3433	1.7433
Middle of container	2.3000	1.4000	3.9667	1.00000	1.03333	1.1767	1.3533	1.9667
Rear of container	2.0667	1.0000	2.7433	1.06667	1.23333	1.3333	1.4000	2.1000
LSD	0.6967	0.4104	1.1929	0.1309	0.2618	0.2979	0.9695	0.3845
Pr > F	0.6026	0.0944	0.0975	0.4444	0.1600	0.3807	0.9852	0.1378

^aRating where 1 = excellent; 2 = good; 3 = acceptable; 4 = poor and 5 = very bad

^bRating where 1 = fresh and green stems; 2 = some light browning; 3 = significant browning; 4 = severe browning

^cRating where 1 = fresh stems, no dry stems; 2 = some drying of thinner stems; 3 = all thinner stems dry; 4 = all thinner stems and some thicker stems dry; 5 = all stems dry

^dRating where 1 = none; 2 = slight damage (<5%); 3 = moderate damage (5-10%); 4 = severe damage (>10%)

^eRating where 1 = none; 2 = slight (<2 infected berries per carton); 3 = severe (2 – 5 infected berries); 4 = extreme (>5 infected berries per carton)

^fRating where 1 = no loose; 2 = < 10 loose berries per carton; 3 = 10-20 loose berries per carton; 4 = > 20 loose berries per carton

Table 2: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to 1.5°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.8556	1.6222	4.10000	1.10000	1.10000	1.10000	1.4000	2.5222
Middle of stack	2.4889	2.1444	4.22222	1.06667	1.17778	1.11111	1.4333	2.0333
Back of stack	2.5556	1.7000	3.98889	1.00000	1.03333	1.10000	1.5444	2.5111
LSD	0.8415	0.9958	0.2281	0.1511	0.2152	0.2281	0.4456	0.5646
<i>Pr > F</i>	0.4992	0.3824	0.1098	0.2844	0.2860	0.9879	0.6696	0.1203
Container position								
Front of container	2.7778	1.9333	4.24444	1.03333	1.10000	1.06667	1.5778	2.2111
Middle of container	2.3778	1.8111	4.07778	1.03333	1.11111	1.03333	1.4444	2.1444
Rear of container	2.7444	1.7222	3.98889	1.10000	1.10000	1.21111	1.3556	2.7111
LSD	0.8415	0.9958	0.2281	0.1511	0.2152	0.2281	0.4456	0.5646
<i>Pr > F</i>	0.4237	0.8458	0.0819	0.4444	0.9864	0.1853	0.4531	0.0908

^{a-f} “Ratings, as defined in Table 1”.

Table 3: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to 3°C (2005/06 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.4556	1.6222	3.5556	1.03333	1.1778	1.1778	1.3889	2.3444
Middle of stack	2.5889	1.4111	4.2556	1.00000	1.1556	1.1444	1.5111	2.7000
Back of stack	2.2444	1.4111	3.4444	1.00000	1.0333	1.0333	1.4000	2.5556
LSD	0.9304	0.4624	1.1717	0.0756	0.3865	0.3995	0.8654	0.7582
<i>Pr > F</i>	0.6214	0.4241	0.2299	0.4444	0.5809	0.6139	0.9122	0.4898
Container position								
Front of container	2.0333	1.3778	3.5444	1.00000	1.2222	1.2889	1.5111	2.6222
Middle of container	2.7778	1.7444	3.8556	1.03333	1.0778	1.0333	1.3556	2.4444
Rear of container	2.4778	1.3222	3.8556	1.00000	1.0667	1.0333	1.4333	2.5333
LSD	0.9304	0.4624	1.1717	0.0756	0.3865	0.3995	0.8654	0.7582
<i>Pr > F</i>	0.1977	0.1191	0.7168	0.4444	0.5187	0.2376	0.8862	0.8176

^{a-f} “Ratings, as defined in Table 1”.

Table 4: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to 1.5 °C (2005/06 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	1.000	1.9630	3.1852	1.000	1.000	1.000	1.000	1.92593
Middle of container	1.000	2.0000	3.1111	1.000	1.000	1.000	1.000	2.00000
Rear of container	1.000	1.8889	2.4444	1.000	1.000	1.000	1.000	1.96296
LSD	0	0.7935	0.7618	0	0	0	0	0.1655
<i>Pr > F</i>	-	0.9415	0.1014	-	-	-	-	0.5787

^{a-f} “Ratings, as defined in Table 1”.

Table 5: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to 3 °C (2005/06 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	1.000	1.6296	2.7778	1.000	1.000	1.000	1.000	1.8148
Middle of container	1.000	1.7778	3.1111	1.000	1.000	1.000	1.000	1.7037
Rear of container	1.000	1.5185	2.5926	1.000	1.000	1.000	1.000	2.1111
LSD	0	0.7654	1.02	0	0	0	0	0.5684
<i>Pr > F</i>	-	0.7209	0.4941	-	-	-	-	0.2696

^{a-f} “Ratings, as defined in Table 1”.

Table 6: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 3°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.3333	1.6667	1.3333	1.0000	1.1667	1.8333	1.0000	2.0000
Middle of stack	2.6667	1.8333	1.5000	1.0000	1.0000	2.1667	1.0000	1.8333
Back of stack	2.0000	1.3333	1.0000	1.0000	1.0000	1.6667	1.0000	2.0000
LSD	1.4633	1.3623	1.5113	0	0.3778	1.7107	0	0.3378
<i>Pr > F</i>	<i>0.5102</i>	<i>0.6208</i>	<i>0.6732</i>	-	<i>0.4444</i>	<i>0.7296</i>	-	<i>0.4444</i>
Container position								
Front of container	2.6667	2.1667	1.3333	1.0000	1.0000	2.1667	1.0000	2.0000
Middle of container	1.8333	1.5000	1.5000	1.0000	1.0000	1.5000	1.0000	1.8333
Rear of container	2.5000	1.1667	1.0000	1.0000	1.1667	2.0000	1.0000	2.0000
LSD	1.4633	1.3623	1.5113	0	0.3778	1.7107	0	0.3778
<i>Pr > F</i>	<i>0.3460</i>	<i>0.2318</i>	<i>0.6732</i>	-	<i>0.4444</i>	<i>0.5765</i>	-	<i>0.4444</i>

^{a-f} “Ratings, as defined in Table 1”.

Table 7: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	3.0000	2.5000	1.6667	1.0000	1.1667	1.1667	1.6667	2.1667
Middle of stack	2.6667	2.1667	2.0000	1.0000	1.1667	1.0000	1.1667	2.0000
Back of stack	2.6667	2.5000	2.3333	1.0000	1.0000	1.3333	1.0000	3.1667
LSD	0.7557	1.4387	2.017	0	0.5974	0.6544	1.1015	1.1948
<i>Pr > F</i>	0.4444	0.7723	0.6824	-	0.6944	0.4444	0.3211	0.1008
Container position								
Front of container	2.8333	2.8333	2.6667	1.0000	1.1667	1.1667	1.5000	1.8333
Middle of container	3.0000	2.5000	1.8333	1.0000	1.0000	1.1667	1.3333	2.8333
Rear of container	2.5000	1.8333	1.5000	1.0000	1.1667	1.1667	1.0000	2.6667
LSD	0.7557	1.4387	2.017	0	0.5974	0.6544	1.1015	1.1948
<i>Pr > F</i>	0.2844	0.2588	0.3525	-	0.6944	1.0000	0.5017	0.1538

^{a-f} “Ratings, as defined in Table 1”.

Table 8: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 1.5 °C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.8333	2.5000	3.0000	1.0000	1.0000	1.3333	1.1667	2.0000
Middle of stack	3.0000	2.0000	2.1667	1.1667	1.1667	1.3333	1.5000	2.8333
Back of stack	3.0000	2.5000	2.3333	1.0000	1.0000	1.3333	1.0000	2.0000
LSD	0.5974	1.3088	2.4486	0.3778	0.3778	1.3088	0.8861	1.5113
<i>Pr > F</i>	0.6944	0.5289	0.6400	0.4444	0.4444	1.0000	0.3735	0.3152
Container position								
Front of container	3.1667	2.6667	3.3333	1.0000	1.0000	1.5000	1.3333	2.0000
Middle of container	2.6667	2.0000	1.6667	1.0000	1.1667	1.3333	1.1667	2.3333
Rear of container	3.0000	2.3333	2.5000	1.1667	1.0000	1.1667	1.1667	2.5000
LSD	0.5974	1.3088	2.4486	0.3778	0.3778	1.3088	0.8861	1.5113
<i>Pr > F</i>	0.1736	0.4444	0.2791	0.4444	0.4444	0.7901	0.8403	0.6732

^{a-f} "Ratings, as defined in Table 1".

Table 9: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to -0.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.0000	1.5000	1.1667	1.0000	1.0000	1.1667	1.0000	2.0000
Middle of stack	2.0000	2.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.3333
Back of stack	2.1667	2.0000	1.0000	1.0000	1.1667	1.0000	1.1667	1.3333
LSD	0.5974	0.6544	0.3778	0	0.3778	0.3778	0.3778	0.9996
<i>Pr > F</i>	0.6944	0.1600	0.4444	-	0.4444	0.4444	0.4444	0.2178
Container position								
Front of container	1.8333	1.8333	1.0000	1.0000	1.0000	1.1667	1.0000	2.0000
Middle of container	2.3333	2.0000	1.1667	1.0000	1.1667	1.0000	1.1667	1.1667
Rear of container	2.0000	1.6667	1.0000	1.0000	1.0000	1.0000	1.0000	1.5000
LSD	0.5974	0.6544	0.3778	0	0.3778	0.3778	0.3778	0.9996
<i>Pr > F</i>	0.1736	0.4444	0.4444	-	0.4444	0.4444	0.4444	0.1800

^{a-f} “Ratings, as defined in Table 1”.

Table 10: Effect of position in the pre-cooling stack and the reefer container on the arrival quality of ‘Victoria’ table grapes that were pre-cooled to 1.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	1.5000	1.6667	1.0000	1.0000	1.0000	1.1667	1.0000	1.5000
Middle of stack	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.6667
Back of stack	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.3333
LSD	0.6544	0.7557	0	0	0	0.3778	0	0.9255
<i>Pr > F</i>	0.1600	0.1111	-	-	-	0.4444	-	0.6400
Container position								
Front of container	1.1667	1.3333	1.0000	1.0000	1.0000	1.6667	1.0000	1.6667
Middle of container	1.3333	1.3333	1.0000	1.0000	1.0000	1.0000	1.0000	1.5000
Rear of container	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.3333
LSD	0.6544	0.7557	0	0	0	0.3778	0	0.9255
<i>Pr > F</i>	0.4444	0.4444	-	-	-	0.4444	-	0.6400

^{a-f} “Ratings, as defined in Table 1”.

Table 11: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of ‘Victoria’ table grapes that were pre-cooled to -0.5°C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	2.6667	1.8333	1.6667	1.0000	1.0000	1.1667	1.1667	3.0000
Middle of stack	2.3333	1.8333	1.8333	1.0000	1.0000	1.1667	1.0000	2.6667
Back of stack	2.5000	1.5000	1.5000	1.0000	1.3333	1.0000	1.1667	2.5000
LSD	0.9255	0.9996	1.851	0	0.7557	0.5974	0.5974	1.7107
<i>Pr > F</i>	0.6400	0.6049	0.8858	-	0.4444	0.6944	0.6944	0.7296
Container position								
Front of container	2.6667	1.8333	1.8333	1.0000	1.0000	1.1667	1.1667	2.1667
Middle of container	2.5000	1.6667	1.6667	1.0000	1.3333	1.0000	1.0000	3.0000
Rear of container	2.3333	1.6667	1.5000	1.0000	1.0000	1.1667	1.1667	3.0000
LSD	0.9255	0.9996	1.851	0	0.7557	0.5974	0.5974	1.7107
<i>Pr > F</i>	0.6400	0.8711	0.8858	-	0.4444	0.6944	0.6944	0.3859

^{a-f} “Ratings, as defined in Table 1”.

Table 12: Effect of position in the pre-cooling stack and the reefer container on the quality (4 weeks after arrival) of 'Victoria' table grapes that were pre-cooled to 3 °C (2006/07 season).

Stack position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front near fan	3.0000	2.1667	2.0000	1.0000	1.0000	1.5000	1.0000	1.8333
Middle of stack	3.3333	2.6667	3.3333	1.0000	1.0000	2.6667	1.0000	2.0000
Back of stack	3.1667	2.5000	2.8333	1.0000	1.0000	1.6667	1.0000	2.1667
LSD	0.4627	1.1015	2.1036	0	0	1.3623	0	1.7314
<i>Pr > F</i>	0.2500	0.5017	0.3120	-	-	0.1420	-	0.8711
Container position								
Front of container	3.3333	2.6667	3.0000	1.0000	1.0000	2.0000	1.0000	2.0000
Middle of container	3.1667	2.5000	2.6667	1.0000	1.0000	1.6667	1.0000	2.0000
Rear of container	3.0000	2.1667	2.5000	1.0000	1.0000	2.1667	1.0000	2.0000
LSD	0.4627	1.1015	2.1036	0	0	1.3623	0	1.7314
<i>Pr > F</i>	0.2500	0.5017	0.8074	-	-	0.6208	-	1.0000

^{a-f} "Ratings, as defined in Table 1".

Table 13: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to -0.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.0000	2.5000	2.0000	1.0000	1.1667	1.8333	1.0000	1.0000
Middle of container	2.5000	2.5000	2.0000	1.0000	1.1667	1.5000	1.1667	1.0000
Rear of container	2.3333	2.6667	2.5000	1.0000	1.0000	1.3333	1.0000	1.0000
LSD	0.666	0.881	0.5767	0	0.4709	0.4709	0.333	0
<i>Pr > F</i>	0.2519	0.8697	0.1250	-	0.6297	0.0983	0.4219	-

^{a-f} “Ratings, as defined in Table 1”.

Table 14: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.1667	2.6667	2.5000	1.0000	1.0000	1.1667	1.1667	1.0000
Middle of container	2.1667	2.6667	2.3333	1.0000	1.5000	1.3333	1.0000	1.0000
Rear of container	2.0000	2.6667	2.3333	1.0000	1.3333	1.0000	1.0000	1.0000
LSD	0.4709	0.9989	1.4891	0	0.881	0.7446	0.333	0
<i>Pr > F</i>	0.6297	1.0000	0.9516	-	0.4219	0.5787	0.4219	-

^{a-f} "Ratings, as defined in Table 1".

Table 15: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to 3 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.1667	2.3333	2.1667	1.0000	1.0000	1.0000	1.0000	1.0000
Middle of container	2.0000	2.0000	2.1667	1.0000	1.0000	1.3333	1.0000	1.3333
Rear of container	1.8333	1.8333	1.8333	1.0000	1.0000	1.0000	1.1667	1.3333
LSD	0.4709	0.9418	0.9989	0	0	0.333	0.333	0.7446
<i>Pr > F</i>	0.2963	0.4640	0.6607	-	-	0.0787	0.4219	0.492

^{a-f} “Ratings, as defined in Table 1”.

Table 16: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to -0.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.0000	3.5000	2.8333	2.8333	1.0000	2.8333	2.0000	1.0000
Middle of container	2.0000	2.6667	2.8333	3.0000	1.0000	3.0000	1.8333	1.0000
Rear of container	2.0000	3.6667	3.0000	3.1667	1.0000	3.1667	1.8333	1.0000
LSD	1.9979	1.1044	0.4709	1.7932	0	1.7932	1.7932	0
Pr > F	<i>1.0000</i>	<i>0.1371</i>	<i>0.6297</i>	<i>0.2963</i>	-	<i>0.9033</i>	<i>0.9663</i>	-

^{a-f} “Ratings, as defined in Table 1”.

Table 17: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to 1.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	3.3333	3.0000	3.0000	1.1667	2.6667	1.8333	1.5000	1.8333
Middle of container	3.1667	3.0000	3.0000	1.0000	2.8333	1.3333	1.0000	2.0000
Rear of container	3.1667	2.8333	2.5000	1.0000	2.8333	1.5000	1.0000	1.0000
LSD	1.1535	0.333	1.4127	0.333	1.2896	1.7932	0.5767	0.881
<i>Pr > F</i>	0.9211	0.4219	0.6297	0.4219	0.9362	0.7928	0.1250	0.0659

^{a-f} “Ratings, as defined in Table 1”.

Table 18: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to $-0.5\text{ }^{\circ}\text{C}$ (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.0000	2.0000	2.0000	1.0000	1.0000	1.1667	1.1667	1.0000
Middle of container	2.0000	2.0000	2.0000	1.0000	1.0000	1.1667	1.1667	1.0000
Rear of container	2.3333	2.0000	2.0000	1.0000	1.0000	1.3333	1.0000	1.0000
LSD	0.666	0	0	0	0	0.5767	0.4709	0
<i>Pr > F</i>	0.4219	-	-	-	-	0.7290	0.6297	-

^{a-f} “Ratings, as defined in Table 1”.

Table 19: Effect of position in the reefer container on the arrival quality of 'Regal Seedless' table grapes that were pre-cooled to 1.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.0000	2.0000	2.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Middle of container	2.1667	2.0000	2.0000	1.0000	1.1667	1.1667	1.1667	1.0000
Rear of container	1.6667	1.8333	1.8333	1.0000	1.0000	1.0000	1.0000	1.0000
LSD	0.7446	0.333	0.333	0	0.333	0.333	0.333	0
<i>Pr > F</i>	0.3170	0.4219	0.4219	-	0.4219	0.4219	0.4219	-

^{a-f} "Ratings, as defined in Table 1".

Table 20: Effect of position in the reefer container on the arrival quality of ‘Regal Seedless’ table grapes that were pre-cooled to 3 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.0000	1.6667	2.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Middle of container	2.0000	1.5000	2.0000	1.0000	1.0000	1.1667	1.0000	1.0000
Rear of container	1.6667	1.5000	1.5000	1.0000	1.0000	1.1667	1.0000	1.0000
LSD	0.881	0.881	0.5767	0	0	0.4709	0	1.1535
<i>Pr > F</i>	0.5927	0.8697	0.1250	-	-	0.6297	-	0.1250

^{a-f} “Ratings, as defined in Table 1”.

Table 21: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to 1.5 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.8333	2.1667	2.3333	1.0000	2.3333	1.0000	1.3333	1.3333
Middle of container	2.6667	2.5000	2.5000	1.0000	2.3333	1.3333	1.0000	2.0000
Rear of container	2.5000	2.3333	2.3333	1.0000	1.1667	1.1667	1.1667	1.0000
LSD	1.8836	0.9418	1.1044	0	1.9128	0.4709	0.7446	2.106
<i>Pr > F</i>	0.9118	0.7023	0.9143	-	0.2993	0.2963	0.5787	0.5330

^{a-f} “Ratings, as defined in Table 1”.

Table 22: Effect of position in the reefer container on the quality (4 weeks after arrival) of ‘Regal Seedless’ table grapes that were pre-cooled to 3 °C (2006/07 season).

Container position	Appearance ^a	Stem browning ^b	Dry stems ^c	SO ₂ burn ^d	Decay ^e	Berry skin browning ^d	Berry flesh browning ^d	Berry shatter ^f
Front of container	2.3333	2.1667	2.3333	1.0000	1.3333	1.0000	1.0000	2.3333
Middle of container	2.3333	2.8333	3.0000	1.0000	1.1667	1.0000	1.0000	3.1667
Rear of container	3.0000	2.1667	2.1667	1.0000	1.0000	1.5000	1.5000	1.6667
LSD	1.3729	0.9989	0.7446	0	0.4709	0.9989	0.5767	1.9979
<i>Pr > F</i>	0.4410	0.2476	0.0723	-	0.2963	0.4219	0.1250	0.2610

^{a-f} “Ratings, as defined in Table 1”.



Figure 1: Picture showing stem browning in 'Regal Seedless' table grapes



Figure 2: Picture showing berry flesh browning in 'Victoria' table grapes

APPENDIX B: SELECTED DATA AND PICTURES FROM ARTICLE II

- Figure 1: Thermal mapping of pulp temperature in a first 40' reefer container set at a delivery air temperature (DAT) of -0.5 °C.
- Figure 2: Thermal mapping of pulp temperature in a second 40' reefer container set at a delivery air temperature (DAT) of -0.5 °C.
- Figure 3: Thermocron® iButton® DS1921Z-F5, which was used to measure pulp and air temperature.
- Figure 4: Placement of the Thermocron button in a 'Red Globe' berry to measure pulp temperatures.
- Figure 7: Air temperature and relative humidity (%RH) in a 40' reefer container1.
- Figure 8: Air temperature and relative humidity (%RH) in a 40' reefer container2.

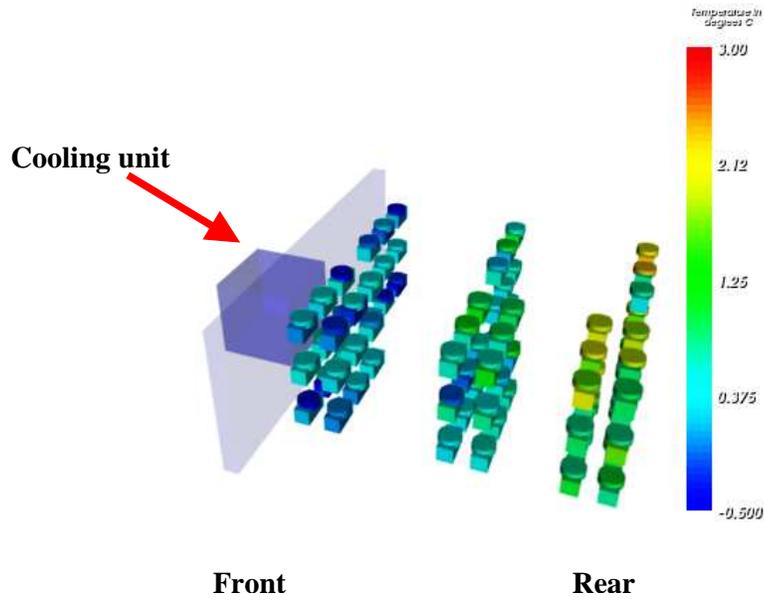


Figure 1: Thermal mapping of pulp temperature in a first 40' reefer container set at a delivery air temperature (DAT) of -0.5 °C.

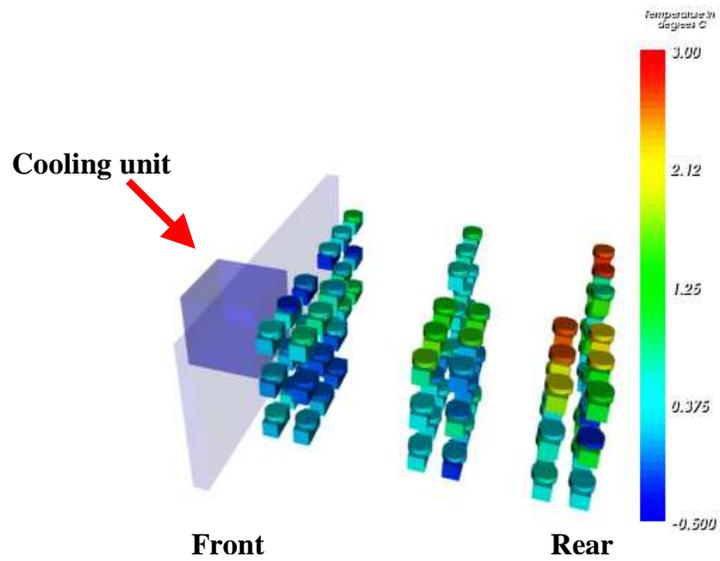


Figure 2: Thermal mapping of pulp temperature in a second 40' reefer container set at a delivery air temperature (DAT) of -0.5 °C.



Figure 3: ThermoCron® iButton® DS1921Z-F5, which was used to measure pulp and air temperature.

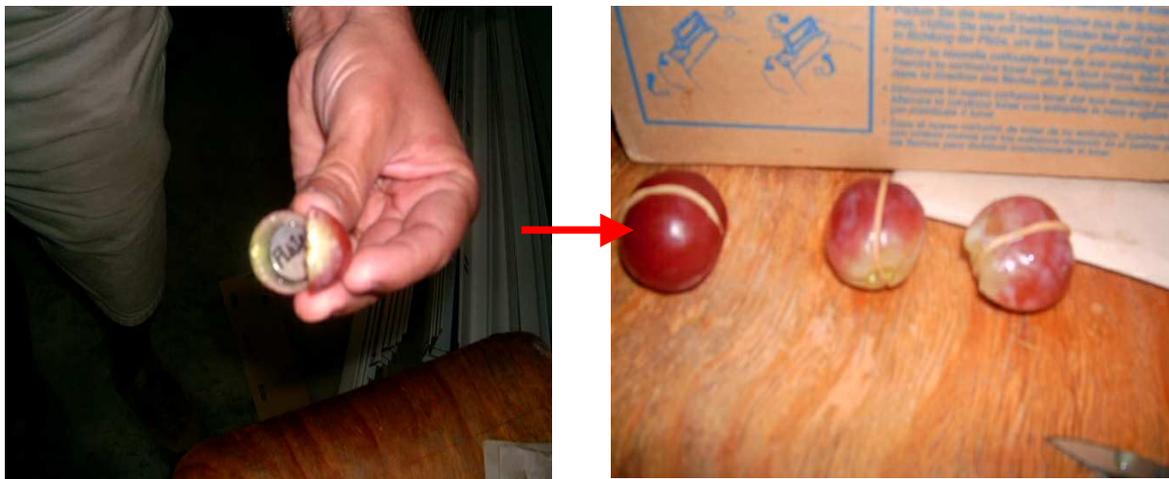


Figure 4: Placement of the ThermoCron button in a 'Red Globe' berry to measure pulp temperatures.

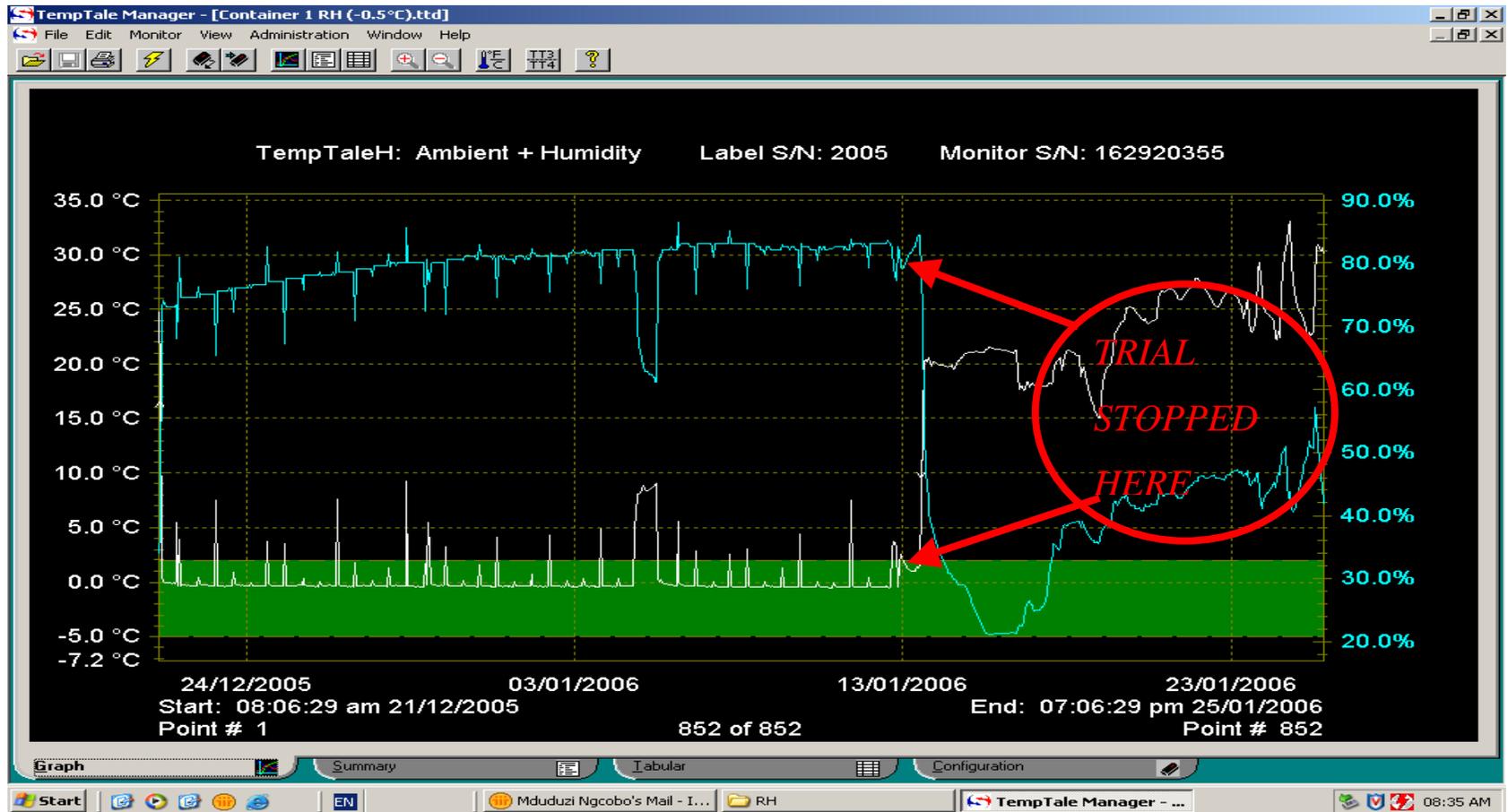


Figure 7: Air temperature and relative humidity (%RH) in a 40' reefer container1.



Figure 8: Air temperature and relative humidity (%RH) in a 40' reefer container2.

APPENDIX C: SELECTED DATA OF ARTICLE III

Table 1: ANOVA Results, Victoria skin leakage.

Table 2: Treatment*Week; LS Means (Victoria skin leakage).

Table 3: ANOVA Results: Victoria Pulp leakage.

Table 4: Treatment*Week; LS Means (Victoria pulp leakage).

Table 5: ANOVA Results: Regal seedless skin leakage.

Table 6: Treatments*Week; LS Means (DATA Regal seedless skin leakage).

Table 7: ANOVA Results, Regal seedless pulp leakage.

Table 8: Treatments*Week; LS Means (DATA Regal seedless pulp leakage)

Table 1: ANOVA Results, Victoria skin leakage.

Effects	Univariate Tests of Significance for Skin leakage Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercepts	123448.9	1	123448.9	41162.64	0.000000
Treatments	282.1	3	94.0	31.36	0.000000
Week	624.4	2	312.1	104.06	0.000000
Treatments*Week	2429.4	6	404.9	135.01	0.000000
Error	179.9	60	3.0		

Table 2: Treatment*Week; LS Means (Victoria skin leakage).

Treatment*Week; LS Means (Victoria leakage DATA1 20070315.sta) Current effect: F(6, 60)=135.01, p=0.0000 Effective hypothesis decomposition							
Cell No.	Treatment	Week	%SKINleakage Mean	%SKINleakage Std.Err.	%SKINleakage -95.00%	%SKINleakage +95.00%	N
1	1	0	35.07924	0.706995	33.66504	36.49344	6
2	1	2	39.41535	0.706995	38.00115	40.82955	6
3	1	4	42.74114	0.706995	41.32694	44.15534	6
4	2	0	57.58509	0.706995	56.17089	58.99929	6
5	2	2	31.66680	0.706995	30.25260	33.08100	6
6	2	4	31.19687	0.706995	29.78267	32.61107	6
7	3	0	44.72270	0.706995	43.30850	46.13690	6
8	3	2	46.24053	0.706995	44.82633	47.65473	6
9	3	4	41.81175	0.706995	40.39755	43.22595	6
10	4	0	44.73108	0.706995	43.31688	46.14528	6
11	4	2	42.09942	0.706995	40.68522	43.51362	6
12	4	4	39.59825	0.706995	38.18405	41.01245	6

Table 3: ANOVA Results: Victoria Pulp leakage.

Effects	Univariate Tests of Significance for %Pulp leakage Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	P
Intercepts	401805.0	1	401805.0	57651.95	0.000000
Treatments	2604.9	3	868.3	124.59	0.000000
Week	562.6	2	281.3	40.36	0.000000
Treatments*Week	1206.8	6	201.1	28.86	0.000000
Error	418.2	60	7.0		

Table 4: Treatment*Week; LS Means (Victoria pulp leakage).

Treatment*Week; LS Means (Victoria leakage DATA1 20070315.sta) Current effect: F(6, 60)=28.858, p=.00000 Effective hypothesis decomposition							
Cell No.	Treatment	Week	%PULPleakage Mean	%PULPleakage Std.Err.	%PULPleakage -95.00%	%PULPleakage +95.00%	N
1	1	0	65.21487	1.077767	63.05901	67.37072	6
2	1	2	70.35155	1.077767	68.19569	72.50741	6
3	1	4	62.94067	1.077767	60.78482	65.09653	6
4	2	0	82.10964	1.077767	79.95379	84.26550	6
5	2	2	72.83068	1.077767	70.67483	74.98654	6
6	2	4	65.20658	1.077767	63.05073	67.36244	6
7	3	0	88.29111	1.077767	86.13525	90.44697	6
8	3	2	75.71473	1.077767	73.55888	77.87059	6
9	3	4	84.73967	1.077767	82.58382	86.89553	6
10	4	0	76.50371	1.077767	74.34785	78.65956	6
11	4	2	80.66566	1.077767	78.50980	82.82151	6
12	4	4	71.87413	1.077767	69.71827	74.02998	6

Table 5: ANOVA Results: Regal seedless skin leakage.

Effects	Univariate Tests of Significance for Skin leakage Sigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercepts	171074.4	1	171074.4	55942.43	0.000000
Treatments	92.0	3	30.7	10.03	0.000019
Week	239.7	2	119.8	39.19	0.000000
Treatments*Week	886.0	6	147.7	48.29	0.000000
Error	183.5	60	3.1		

Table 6: Treatments*Week; LS Means (DATA Regal seedless skin leakage).

Treatments*Week; LS Means (DATA RGT leakage 20070315.sta)							
Current effect: F(6, 60)=48.290, p=0.0000							
Effective hypothesis decomposition							
Cell No.	Treatments	Week	SKINleakage Mean	SKINleakage Std.Err.	SKINleakage -95.00%	SKINleakage +95.00%	N
1	1	0	46.57405	0.713914	45.14601	48.00209	6
2	1	2	44.38090	0.713914	42.95286	45.80894	6
3	1	4	51.65345	0.713914	50.22541	53.08149	6
4	2	0	51.33214	0.713914	49.90410	52.76018	6
5	2	2	51.16717	0.713914	49.73913	52.59522	6
6	2	4	42.68743	0.713914	41.25939	44.11547	6
7	3	0	47.31655	0.713914	45.88851	48.74459	6
8	3	2	48.87663	0.713914	47.44859	50.30467	6
9	3	4	55.60547	0.713914	54.17743	57.03351	6
10	4	0	47.30487	0.713914	45.87683	48.73291	6
11	4	2	43.09633	0.713914	41.66829	44.52437	6
12	4	4	54.93980	0.713914	53.51176	56.36784	6

Table 7: ANOVA Results, Regal seedless pulp leakage.

Effects	Univariate Tests of Significance for Pulp leakage				
	Sigma-restricted parameterization				
	Effective hypothesis decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercepts	393140.9	1	393140.9	74255.93	0.000000
Treatments	281.9	3	94.0	17.75	0.000000
Week	515.4	2	257.7	48.67	0.000000
Treatments*Week	1127.4	6	187.9	35.49	0.000000
Error	317.7	60	5.3		

Table 8: Treatments*Week; LS Means (DATA Regal seedless pulp leakage).

Treatments*Week; LS Means (DATA RGT leakage 20070315.sta)							
Current effect: F(6, 60)=35.490, p=0.0000							
Effective hypothesis decomposition							
Cell No.	Treatments	Week	PULPleakage Mean	PULPleakage Std.Err.	PULPleakage -95.00%	PULPleakage +95.00%	N
1	1	0	80.26841	0.939362	78.38941	82.14741	6
2	1	2	71.05214	0.939362	69.17314	72.93115	6
3	1	4	74.96055	0.939362	73.08154	76.83955	6
4	2	0	78.40267	0.939362	76.52366	80.28167	6
5	2	2	69.27022	0.939362	67.39122	71.14923	6
6	2	4	65.58457	0.939362	63.70557	67.46358	6
7	3	0	78.90022	0.939362	77.02121	80.77922	6
8	3	2	70.95367	0.939362	69.07467	72.83267	6
9	3	4	78.29618	0.939362	76.41718	80.17518	6
10	4	0	72.60626	0.939362	70.72725	74.48526	6
11	4	2	80.44435	0.939362	78.56534	82.32335	6
12	4	4	65.98611	0.939362	64.10711	67.86512	6