

Temperature Variances in a 12 m Integral Reefer Container Carrying Plums under a Dual Temperature Shipping Regime

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Abstract

The South African plum industry is an important supplier of fresh fruit to the northern hemisphere from December to April. Extensive use is made of a dual-temperature shipping regime, which is a form of intermittent warming, in order to limit the occurrence of chilling-related internal defects like gel breakdown (GB) and internal browning (IB). The perception in industry is that use of the 12 m integral reefer containers leads to more quality defects than are experienced in conventional reefer vessels using the same temperature regimes. It was hypothesised that there are significant temperature variances in the integral reefers and three pallets of Sapphire plums were therefore wired with thermocouples to log pulp and air temperatures during commercial shipping to the United Kingdom. Results indicated that the delivery air temperature (DAT) was very close to the set point, and that the container therefore had the refrigeration capacity to maintain the DAT within acceptable tolerances. Air temperatures within the pallets, however, varied significantly, with peaks of up to 12°C at a set point of 7.5°C. The fruit pulp temperatures showed similar deviations. As expected, fruit in the pallet closest to the doors showed the slowest reaction to changes in temperature, and those in the pallet closest to the cooling unit, the most rapid. Fruit in the 4th layer on the pallet, closest to the base of the pallet, reacted fastest to changes in set point, and fruit in the 10th layer, close to the middle of the pallet, generally reacted the slowest. All fruit were deemed 'ripe and ready to eat' upon arrival, and no IB or GB were found. Mention was made, however, of significant levels of shrivel, which may have been aggravated by the fairly low relative humidity in the container. Further trials are underway to investigate the relationship between fruit quality and the temperature gradients in reefer containers, using cultivars with differing metabolic rates.

INTRODUCTION

The South African plum industry is an important supplier of fresh fruit to the Northern Hemisphere from December to April, annually exporting approximately 8-9 million cartons (5 kg) of Japanese plums (*Prunus salicina* Lindl.). Most of the cultivars are derived from a local breeding program and have been selected for their ability to withstand a minimum shipping and distribution period of five weeks. With only a few exceptions, the fruit are shipped under a dual temperature regime consisting of an initial period at -0.5°C, a variable intermittent warming period at 7.5°C, followed again by -0.5°C. This technique is necessitated by the occurrence of internal disorders such as internal browning (IB) and gel breakdown (GB), which can be described as symptoms of chilling injury. The dual temperature regimes were developed over an extended period of time, dating back initially to the early 1950's (Boyes, 1951; Boyes et al., 1952). At that time, break bulk shipping was commonly used. The introduction of the 12 m integral reefer containers has opened the possibility of a genuine door-to-door service, due to the flexibility of maintaining the cold chain as long as the container is attached to a suitable power supply to drive its refrigeration system. Commercial experience with export of plums in these containers has, however, shown a greater frequency of quality claims from receivers, suggesting that the integral reefers are unsuited to carrying plums under dual

temperature conditions. Previous research by Tanner and Amos (2003) has demonstrated significant temperature variability in shipping loads of fresh produce under constant set point temperatures. This led to the hypothesis that the variability in fruit arrival quality was related to a variability in temperatures experienced by the fruit during the shipping phase, which lasts for approximately 21 days from the point of stuffing the container to discharge by the receivers in the UK or the EU continent. In order to test this hypothesis, a trial was designed to quantify fruit pulp and air temperatures during commercial shipment of plums under dual temperature conditions from South Africa to the UK.

MATERIALS AND METHODS

Sapphire (*Prunus salicina*) plums within the commercial export maturity spectrum of 5.0 to 9.5 kg firmness (11.1 mm penetrometer tip) and soluble solids of 11°Brix were packed in 5.0 kg cartons. The mean firmness was 7.5 kg, with soluble solids of 13°Brix. During packing, type T thermocouples were inserted into the pulp of one fruit per carton, in three cartons per layer on three layers per pallet, viz. layers 4, 10 and 16, representing the bottom, middle and top of each pallet, respectively. There were 18 layers of cartons on the pallet. Additional thermocouples were positioned to measure air temperature in the same positions. Three pallets were wired in this fashion. Thermocouples were connected to Grant Squirrel data loggers programmed to record temperatures every 4 hours. Fruit were forced air-cooled to a pulp temperature of -0.5°C prior to loading into a 12 m integral reefer container. The three wired pallets were loaded so as to monitor temperatures in the front, middle and back end of the container. Additionally, Sensitech humidity and temperature recorders were placed in the T-bar floor, against the return air grille and in the topmost layer of the pallet closest to the door, to log air temperature and relative humidity (RH). A dual temperature shipping regime was used, namely two days at -1°C , five days at 7.5°C and the rest of journey at -1°C (during this particular season, a delivery air temperature (DAT) of -1°C was used instead of -0.5°C in order to counteract possible rises in pulp temperature due to fruit respiration). Fresh air was introduced into the container at $15\text{m}^3\cdot\text{hour}^{-1}$. Upon arrival in the UK, 28 days after packing, 20 plums in the immediate vicinity of thermocouples were evaluated for maturity and internal defects to correlate pulp and air temperatures with fruit quality.

RESULTS AND DISCUSSION

Air Temperatures and Relative Humidity

The DAT was generally within $\pm 0.5^{\circ}\text{C}$ of the set point, as prescribed for exports from South Africa (Eksteen, 2002) (Fig. 1). However, return air temperature (RAT) and air temperature inside the pallets, were substantially warmer. Within all three pallets, there was a prolonged cooling phase associated with the period following the five days at 7.5°C , as represented in Figure 2 which shows the air temperatures in the 10th layer for all three pallets.

Air temperatures at the base of the pallet were fairly close to the set point, especially in the pallet closest to the cooling unit. The further from the cooling unit, however, the higher the temperature, albeit only a small increase (data not shown). Inside the pallet, however, temperatures were substantially higher than at the base. This is illustrated in Figure 3, which shows air temperatures in the pallet located in the middle of the container. The highest air temperatures (approximately $11\text{-}12^{\circ}\text{C}$) were registered in the 10th and 16th layers from the base. Corresponding zones in the pallets positioned closest to the cooling unit and closest to the door were significantly lower (Fig. 2). The only air temperatures that approximated the set point were those in the 4th layer from the base in the pallet closest to the cooling unit as well as the pallet in the centre of the container (Fig. 3).

As to be expected, the change in DAT led to a dramatic fluctuation in RH (Fig. 1). The desired humidity, in excess of 90% (Mitchell and Kader, 1989), was seldom achieved. This is a cause for concern, as fruit is kept in the reefer container for prolonged periods of time and is therefore prone to desiccation.

Fruit Pulp Temperatures

Given the air temperature profiles within the pallets, described above, it is not surprising that fruit pulp temperatures also exceeded the set point by a substantial margin. The increase in pulp temperature during the step-up phase of the regime (from -1°C to 7.5°C) as well as the step-down phase (from 7.5°C to -1°C) was the slowest in the pallet closest to the doors (Fig. 4), particularly in the 10th layer. Fruit in the 4th and 16th layers showed fairly rapid initial cooling after the step-down to -1°C . This may be due to the stacking pattern in the container, which ensures that almost the entire floor space is covered apart from a gap at the door end. Air from the cooling unit passing along the length of the T-bar floor will therefore encounter fairly low resistance at the door end, and the base, one side (door end) and top of those pallets will be exposed to a fairly high volume of air, especially in comparison to the pallets in the middle of the container (Fig. 5). The middle pallets clearly experience a shortage of cooling air apart from the base of the pallet where temperature changes are fairly rapid.

The most rapid cooling rate was achieved in the pallet closest to the cooling unit (Fig. 6), where the change from a DAT of 7.5°C to -1°C led to an immediate drop in pulp temperature in layers 4 and 10.

It took between two and three days for the fruit to warm up to 7.5°C . During the step-up phase, pulp temperatures continued to climb past the set point of 7.5°C in all pallets, to eventually peak at 9.5°C to 11°C . Fruit in the 10th and 16th layers of the pallets peaked at higher temperatures than fruit in the 4th layer (Figs. 4, 5 and 6).

These warming and cooling profiles can be explained on the basis of air distribution in the container, as influenced by the product and packaging. The DAT was clearly well within the required tolerances, indicating that the cooling capacity of the equipment is adequate to maintain the desired set point. However, moving that volume of air down a 12 m integral and through palletised fruit with a high metabolic rate leads to excessive increases in pulp temperature. There is currently almost no provision for vertical air movement through the pallet, and until such changes are made the industry will continue to struggle with temperature maintenance.

Fruit Quality

When comparing the temperature profiles of the pallet closest to the cooling unit (Fig. 6) and the pallet closest to the doors (Fig. 4), one expects that they will have different effects on fruit ripening rate. However, the fruit quality control reports from the receiver in the UK indicated that all fruit were “ripe and ready to eat” upon inspection, with firmnesses below 2.5 kg (8.9 mm penetrometer tip) and peel colour fully developed. It was, therefore, not possible to ascribe any particular maturity to a particular temperature profile. Mention was also made of varying levels of shrivel, regardless of pallet position in the container or carton position in the pallet. It is believed that the fairly low relative humidity during the shipping period contributed significantly to the problem.

There were no internal defects such as IB or GB, but this was to be expected, given the use of the dual temperature regime and the relatively high soluble solids levels of the fruit. However, in fruit with lower soluble solids, which are more inclined to develop internal defects, the exposure to temperatures in the so-called “killing range” of 2.2° to 10°C (Anon, undated) or 2.2° to 7.8°C (Mitchell and Kader, 1989) should lead to severe internal defects like IB or GB. In this case, fruit in pallets closest to the door end are at higher risk as the total time of exposure to this temperature range is greater than experienced by fruit in pallets closer to the cooling unit of the container.

CONCLUSION

This study has illustrated significant temperature gradients within a 12 m integral reefer container shipping Sapphire plums under a dual temperature regime. Undoubtedly, the high respiration rate of Sapphire will have contributed to the peak in pulp temperature reaching $11\text{-}12^{\circ}\text{C}$ and other cultivars are not expected to show quite the same patterns. Further trials are underway to map temperatures and humidities under both dual and

single temperature shipping regimes, and to correlate these with fruit quality in a range of cultivars. Modifications are being made to container air flow patterns through changes to packaging and ventilation in order to reduce temperature variances. These changes are expected to also benefit fruit types other than plums, where problems are often experienced with maintenance of cold sterilisation thresholds.

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Figures

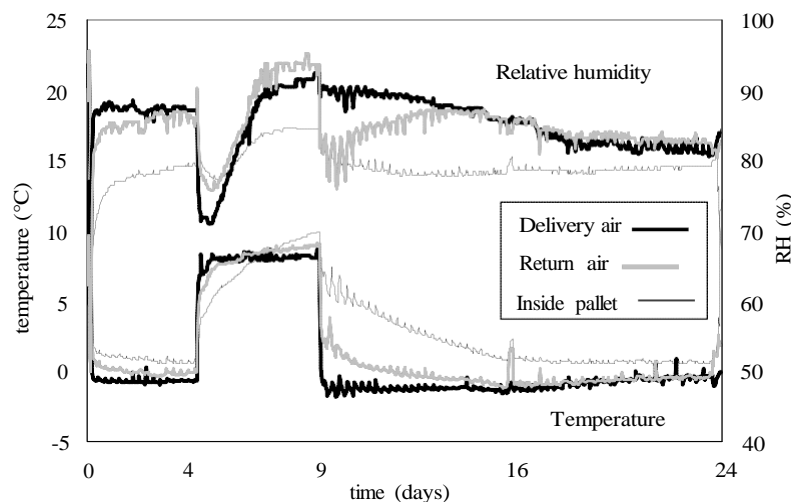


Fig. 1. Air temperature (bottom 3 lines) and relative humidity (top 3 lines) in an integral reefer container carrying plums under a dual temperature shipping regime. 'Inside pallet' refers to pallet closest to the door.

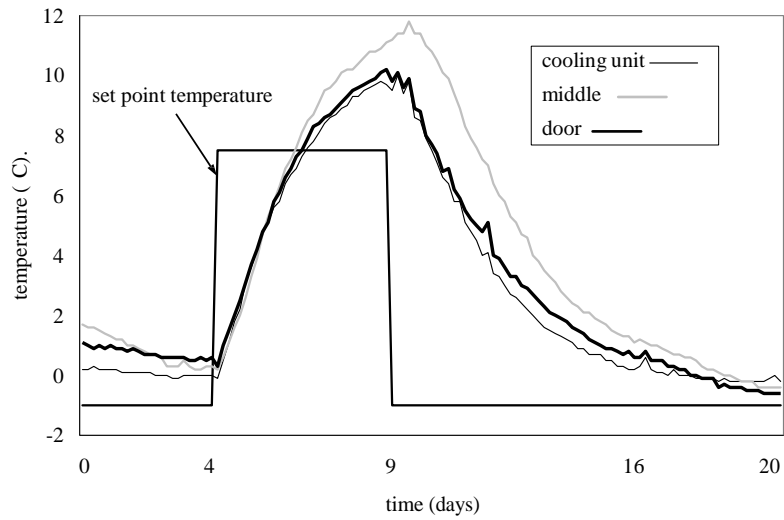


Fig. 2. Air temperature in the 10th layer of the pallets close to the cooling unit, middle of the container and close to the door of an integral reefer container carrying plums under a dual temperature shipping regime.

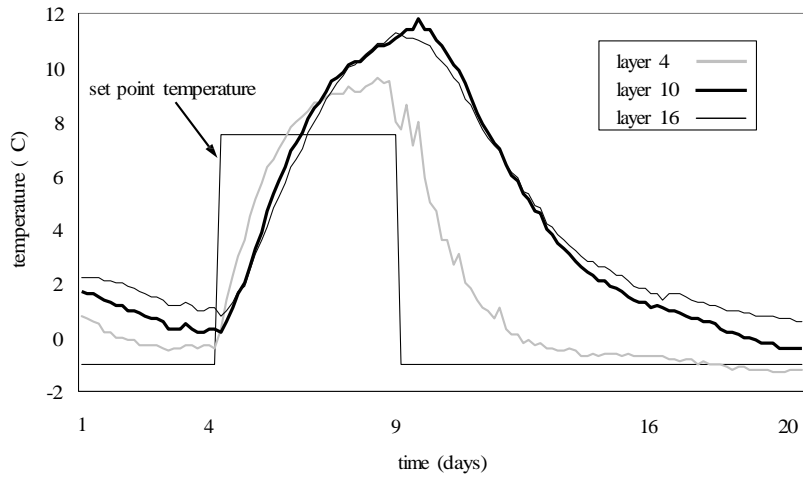


Fig. 3. Air temperatures in the 4th, 10th and 16th layers of the pallet positioned in the middle of an integral reefer container carrying plums under a dual temperature shipping regime.

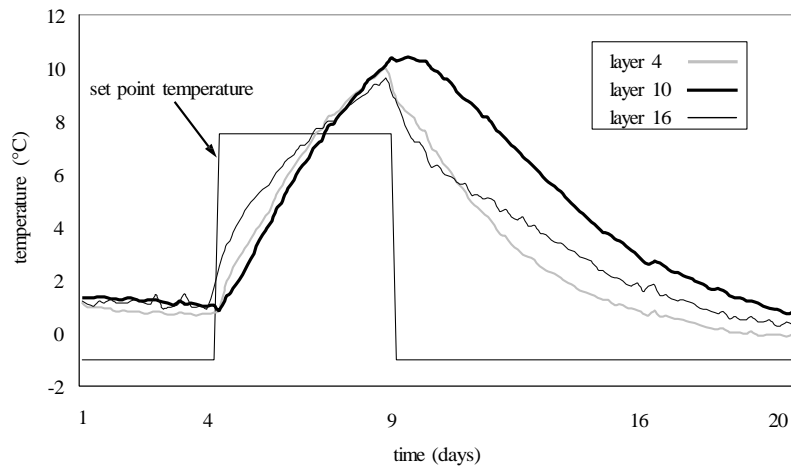


Fig. 4. Pulp temperatures in the 4th, 10th and 16th layers of the pallet positioned closest to the doors of an integral reefer container carrying plums under a dual temperature shipping regime.

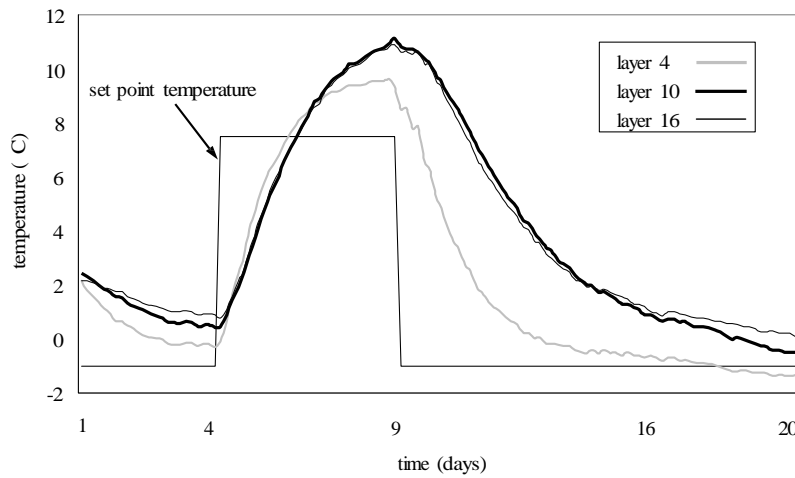


Fig. 5. Pulp temperatures in the 4th, 10th and 16th layers of the pallet positioned in the middle of an integral reefer container carrying plums under a dual temperature shipping regime.

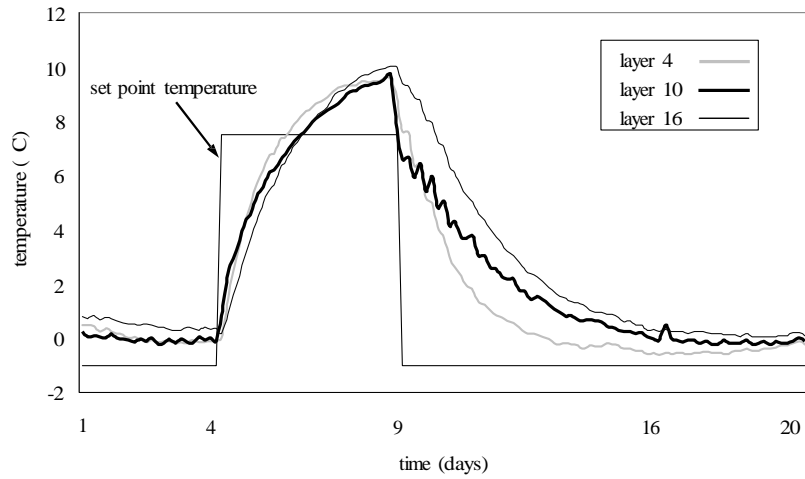


Fig. 6. Pulp temperatures in the 4th, 10th and 16th layers of the pallet positioned closest to the cooling unit of an integral reefer container carrying plums under a dual temperature shipping regime.