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Detecting temperature breaks in the initial stages of the citrus export cold chain: A case study

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Background: Fruit is an important export commodity for South Africa and accounts for 35% of its agricultural exports. South Africa is the second largest citrus exporter in the world, behind Spain. Maintaining the postharvest cold chain is key to ensuring that fruit quality meets export standards.

Objectives: The main objectives of this research were to investigate the frequency, location, magnitude and duration of temperature deviations in the South African leg of the clementine and navel orange cold chain.

Method: Temperature trials were conducted on two consignments of clementines and two consignments of navels. Each consignment contained 36 iButtons®, of which 18 measured pulp temperature and 18 measured ambient temperature. Data were successfully retrieved from 130 of the 144 iButtons®.

Results: This research identified areas where the temperature went outside the prescribed range along the South African portion of the export cold chain of navel oranges and clementines from Citrusdal, South Africa to the Port of Newark, United States of America.

Conclusion: The temperature incidents identified could result in a breach of the cold sterilisation (steri) protocols and quality defects. Recommendations were made to address these deficiencies to improve the South African citrus industry's global competitiveness.

Contribution: This research allowed the citrus industry to investigate and adjust current cold chain practices to improve the integrity of the entire export cold chain, potentially resulting in a higher quality product and increased revenue.

Keywords: Citrus; cold chain; fresh fruit exports; steri; temperature breaks; temperature variations.

Introduction

Maintaining the postharvest cold chain is critical to ensure that fruit quality meets export requirements (Defraeye et al. 2016). Temperature stabilisation, that is, keeping the temperature within a specified range, is an evident challenge in the fresh fruit export cold chain (Zwierzycki et al. 2011).

This study investigated the cold chain stabilisation issue that the South African (SA) citrus industry faces by analysing the frequency, location, magnitude and duration of temperature breaks in the SA leg of the export cold chain, that is, from the farm until the end of the cold sterilisation (steri) protocol, just before vessel loading. Cold sterilisation is a treatment used in the export of fresh fruit to certain markets that includes the abolition of eggs or larvae of pests when exposed to low temperatures (United States Department of Agriculture [USDA] 2018). Cold-sterilisation temperatures range between 0.6 °C and 3 °C, depending on the market and target insect pest (Hordijk 2013; Khumalo et al. 2021). Four temperature trials were conducted, two with clementines and two with navel oranges, for fruit exported from two farms in Citrusdal in the Western Cape, South Africa, to the Port of Newark, New Jersey, in the United States of America (USA). iButton® temperature monitoring devices were used to record ambient and fruit pulp temperatures.

This study expands on the work undertaken by Khumalo (2018), who recommended a further investigation of the SA portion of the citrus export cold chain from Citrusdal to the USA.

South Africa is the second largest citrus exporter in the world, and fruit accounts for 35% of its agricultural exports (Citrus Gowers' Association 2020; FPEF 2021). It is therefore important for the fruit industry to maintain global competitiveness.

The remainder of this article is organised as follows: the 'Theoretical perspective' section provides a brief overview of the SA fruit industry and the citrus industry, the typical citrus export cold chain, the impact of temperature on citrus fruit, the regulatory bodies and previous SA studies, as well as a selection of relevant international best practices and the contribution of this study. The 'Methodology' section outlines the methods that were followed for this study. The results of the four trials are delineated in the 'Results' section, followed by a discussion of the findings in the 'Discussion' section. The last section draws conclusions and offers a few suggestions for further research.

Theoretical perspective

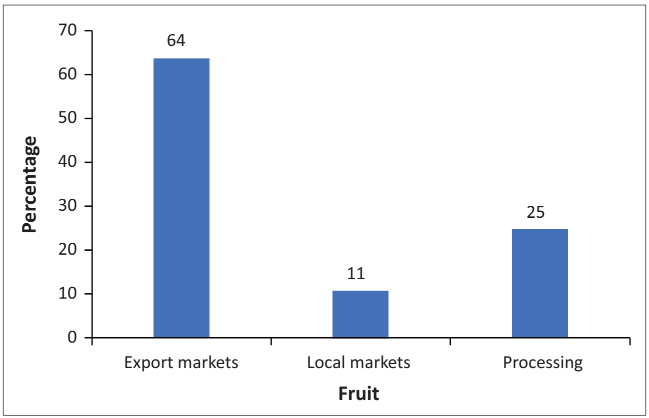
The South African fruit industry

The SA fruit industry exports approximately 3.3 million tons of fruit with a value of R43.8 billion annually (FPEF 2021; FruitSA 2020). It is export driven (Kapuya, Chinembiri & Kalaba 2014), with 64% of the fruit exported, as is shown in Figure 1. It generates significant foreign income, as 90% of the SA fruit industry's income is in the form of foreign exchange (Uys 2016). Furthermore, it is a significant job creator, with 276 647 on-farm employees supporting 1 099 231 dependents in 2020 (FruitSA 2020).

Fruit farmers in South Africa cultivate a large variety of fruit types because of the country's notably suitable agricultural conditions, including table grapes, pome fruit (apples and pears), stone fruit (apricots, nectarines, peaches, plums), citrus (oranges, soft citrus, lemons, grapefruit) and subtropical fruit (avocados, mangoes, litchis).

The South African citrus industry

Citrus accounts for 55% of the total fruit production and 62% of fruit exports, with the season spanning from March until November (FPEF 2021; FruitSA 2020). The main citrus production regions in South Africa are the Eastern Cape, Limpopo, Mpumalanga and the Western Cape (Citrus Growers' Association 2021). Figure 2 depicts South Africa's citrus-producing areas. Citrusdal is located in the Western Cape Province, roughly 180 km from the Port of Cape Town.

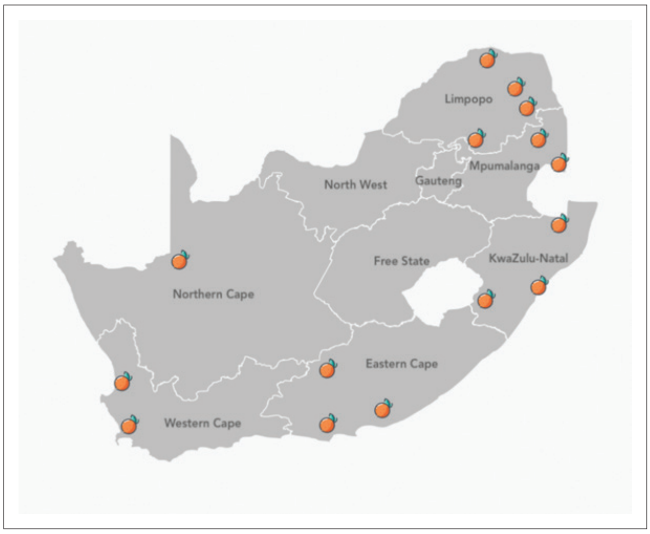


Source: FruitSA, 2020, Fruit SA statistics 2020, viewed 21 April 2022, from https://fruitsa.co.za/wp-content/uploads/2021/11/A5-Fruit-SA-Booklet_2021_Web_FINAL.pdf.

FIGURE 1: Market segmentation of the South African fruit industry.

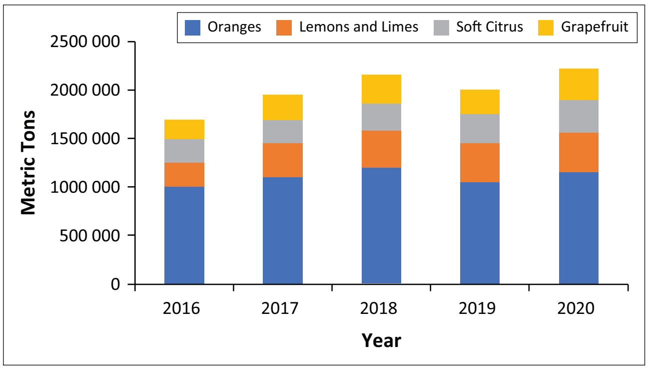
Soft citrus (that is, easy peelers such as clementines) accounts for 48% and navel oranges for 22% of the Western Cape's total annual citrus production. However, in the rest of the country, the segmentation is different and looks as follows – Valencias (31%), followed by soft citrus (25%), lemons and limes (19%), navels (17%) and grapefruit (9%) (Citrus Gowers' Association 2021). Because of the ongoing drought in South Africa, citrus export figures have shown little growth over the last decade. Figure 3 depicts South Africa's total annual citrus exports from 2016 to 2020.

Oranges are South Africa's most exported citrus fruit, followed by lemons and limes, grapefruit and then soft citrus. Lemons, limes and soft citrus have shown growth over the last 5 years, which is one of the reasons why soft citrus is such a popular variety in the Western Cape (Mogala 2016). This is backed up by the fact that soft citrus was the only segment of the citrus industry that experienced significant production and export growth during the SA drought (Citrus Growers' Association 2018).



Source: Adapted from Citrus Growers' Association, 2018, Key industry statistics 2018, viewed 21 April 2022, from http://www.citrusresourcewarehouse.org.za/home/document-home/information/cga-key-industry-statistics/5475-cga-key-industry-statistics-2018/file.

FIGURE 2: South Africa's citrus production areas.



Source: United States Department of Agriculture (USDA), 2020, Citrus annual: Republic of South Africa, viewed 21 April 2022, from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Citrus%20Annual_Pretoria_South%20Africa%20-%20Republic%20of_12-15-2020.

FIGURE 3: South African citrus exports.

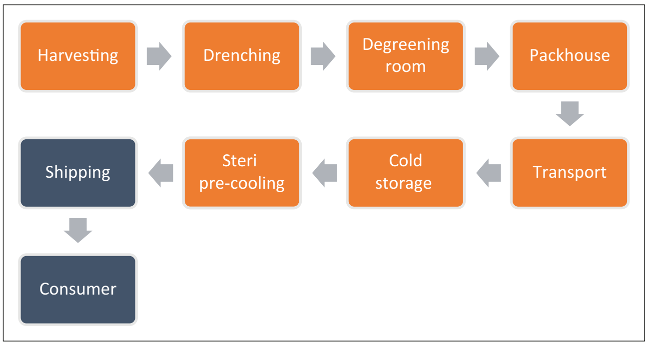
A typical citrus export cold chain

The citrus supply chain starts on the farm during the growing phase, where the fruit requires different treatments during each growth stage. Upon reaching their optimal growth level, the farmer makes the decision to start harvesting. Straight after harvesting, the citrus fruit undergoes a drenching process, which removes field heat and cleans the fruit. In addition, various chemicals are added to the water to eradicate pests and protect the fruit from fungi that cause decay. Normally, the peel is still green when the fruit is harvested, which is an unacceptable market condition. Therefore, farms implement a degreening process, which lasts 2–3 days, depending on the variety and cultivar.

After degreening, packhouses pack the fruit into cartons and palletise them. Larger farms usually pack their own fruit, while smaller farms outsource packing. The pallets are then transported in tautliner trailers from the packhouses to a cold storage facility at the Port of Cape Town. The cold rooms are regulated at a temperature range of between 0 °C and 6 °C (Khumalo 2018). While the pallets are in cold storage, they are removed briefly for inspection of the fruit, which occurs at ambient temperature. After inspection, the pallets are returned to the cold store until it is time to initiate the steri protocol, at which time the pallets are moved with forklifts to the cold sterilisation (steri) chambers. The steri chambers are maintained at standard cold storage temperatures of 0 °C – 6 °C. Once the steri chamber is full, the temperature is set to -0.6 °C. The citrus fruit is kept in the steri chambers for a minimum of 72 h, after which the pallets are loaded onto a reefer vessel, where the steri protocol is continued. When loading has been completed, the vessel sails to the Port of Newark, New Jersey in the USA, where the fruit is distributed according to demand. Figure 4 illustrates a typical citrus export cold chain. This study only covered the orange-coloured stages.

Citrus and temperature

Temperature is regarded as the most important factor affecting the quality of fresh produce postharvest (Lafuente et al. 2005; Thompson 2008). The main reasons for controlling the temperature of citrus fruit are to retard fruit respiration and moisture loss, which prolongs its shelf life.



Source: Adapted from Freiboth, H.W., Goedhals-Gerber, L., Van Dyk, F.E. & Dodd, M.C., 2013, 'Investigating temperature breaks in the summer fruit export cold chain: A case study', Journal of Transport and Supply Chain Management 7(1), a99. https://doi.org/10.4102/jtscm.v7i1.99

FIGURE 4: A typical citrus export cold chain.

Two types of cooling are typically used in tandem in the SA citrus industry. The first is drenching, a form of hydro-cooling, which removes the field heat shortly after harvesting. After the citrus has been packed, the pallets are transported to a cold storage facility where they are cooled with forced-air cooling to -0.6 °C for 72 h, in the case of fruit exported to the USA.

Temperature spikes and temperature breaks have a negative impact on the quality of citrus fruit because they cause moisture loss and accelerate fruit respiration, which shortens the fruit's shelf life (Goedhals-Gerber & Khumalo 2020). A temperature spike occurs when the temperature increases at any point along the export cold chain, whereas a temperature break is defined (for the purpose of this study) as a temperature increase of 2 °C or more for 90 min or longer during the export cold chain. In addition, temperature that gets too cold also has a negative impact on the quality of citrus in terms of possible chilling injury. The fruit was considered at risk of chilling injury (in this study) anytime the temperature was equal to, or dropped below, the threshold of -1.5 °C.

Regulatory organisations

Several organisations strictly regulate the citrus export industry. The two main organisations relevant to this study are the South African Department of Land Reform and Rural Development (DALRRD) and the USDA.

Department of Land Reform and Rural Development

The DALRRD was established in June 2019. It was formed by the merger of the Department of Agriculture, Forestry and Fisheries (DAFF) and the Department of Rural Development and Land Reform (DRDLR) (DALRRD 2022). Alongside the USDA's Animal and Plant Health Inspection Service (USDA – APHIS), DALRRD is responsible for all phytosanitary inspections of fruit exports and the forwarding of interception data. Furthermore, DALRRD ensures that all role players in the export chain implement South Africa's Good Agricultural Practice (GAP) legislation. The DALRRD appointed the Perishable Products Export Control Board (PPECB) to enhance South Africa's exporting credibility and assist them with phytosanitary matters (PPECB 2022).

United States Department of Agriculture

The USDA regulates and inspects agricultural imports and exports for the USA. The organisation consists of 29 agencies, of which the one that is applicable to SA citrus is APHIS. Its Plant Protection Quarantine (PPQ) inspects citrus imports for any irregularities. These inspections occur mainly at the port and cold stores. Animal and Plant Health Inspection Service rejects any consignment containing evidence of irregularities (USDA 2021).

South African studies

This section summarises several previous studies that are of relevance. These studies are from the Stellenbosch University, which conducts extensive research regarding the fruit export cold chain.

The first study was conducted by Freiboth (2012). He investigated the occurrence of temperature breaks in the summer fruit export cold chain to Europe. He analysed historical temperature data obtained from exporters for 196 reefer containers with table grapes, apples and pears, and he also conducted a temperature trial for apples. The historic data measured the ambient temperature inside a reefer container – a temperature monitor is normally placed into a carton of fruit in the pallet nearest to the door before the container is sealed. The monitor is removed when the container is opened at the overseas port or distribution centre (DC). The historic data indicated that 65% of the containers experienced a temperature break while in the container terminal at the Port of Cape Town, while only 8% experienced a temperature break during the transport segment from the inland cold store to the port. Almost a quarter of the breaks occurred between 12:00 and 15:00, that is, during the hottest part of the day.

The apple trial measured the ambient temperature at four pallet positions inside the container. It also compared ambient and fruit pulp temperature at the two ends of the container, that is, at the cooling unit and at the door. The ambient temperature differed with approximately 0.67 °C between the two ends of the container over the entire journey. Furthermore, pulp temperatures inside the container were higher than ambient temperatures as a result of fruit respiration. Although the fruit was cooled to -0.5 °C in the cold store, the pulp temperature reached 0.7 °C during loading and spiked at 1.8 °C by the time the container reached the port. This breached the PPECB export protocol, which stipulates that the fruit pulp temperature be maintained at -0.5 °C (Freiboth et al. 2013).

Freiboth (2012) developed a best practice guide for a deciduous fruit cold chain, of which the basic structure may also apply to citrus cold chains. The guide distinguishes between avoidable and unavoidable breaks and insists that export cold chain role players must eliminate avoidable temperature breaks and minimise unavoidable temperature breaks. For example, by constructing shaded areas, farmers can avoid temperature spikes during the picking phase by eliminating sunlight exposure during the waiting period. Temperature breaks can be minimised during the inspection stage by conducting inspections indoors.

Haasbroek (2013) expanded on Freiboth's research. She analysed temperature data received from exporters for 123 containers with table grapes, plums and summer pears exported to the European Union (EU) and United Kingdom (UK), and she conducted temperature trials for 11 containers (2 pears, 3 plums and 6 table grapes). She also observed processes on farms, in packhouses, in cold stores and at the Port of Cape Town container terminal. A temperature break in the cold chain was defined as any time in the data where the ambient temperature of the air measured within the fruit container rose above 2 °C for longer than 90 min. The optimal storage and transport temperature (pulp temperature) is -0.5 °C for table grapes, -1.5 °C for summer pears and -0.5 °C for plums, in most cases (although it varies according to cultivar and voyage) (Goedhals-Gerber et al. 2015). A total of 183 temperature breaks were identified in the 123 containers – only 13 containers had no breaks. Although a large percentage of containers (49%) only had one break, many of these breaks lasted for more than a day. The transport segment had the largest number of breaks (84), and the reefer stack segment had 60 breaks. Most of the breaks in the transport segment occurred at the beginning of the segment when the fruit was removed from the cold store and loaded into the containers. The observations showed that temperature breaks occur when companies neglect proper cold chain practices in order to reduce the time that the fruit spent in the system to increase the throughput of fruit.

Haasbroek therefore developed a best practice guide in poster format for each segment of the table grape cold chain that contains similar elements to citrus cold chains. For example, the guide insists that farms harvest the fruit during cooler times of day and that the fruit does not wait in the orchard after harvest. Furthermore, various technical elements like keeping packhouses under a certain temperature and insulating the roofs can greatly improve producers' and exporters' cold chain performance.

A further study was undertaken by Stander (2014) to investigate the reasons for temperature breaks inside the Cape Town container terminal. He observed processes inside the container terminal and analysed temperature data received from exporters for 121 containers with table grapes, plums, apples and pears. A total of 142 breaks occurred in the container terminal – only 23 containers had no breaks and 44 containers had one break each. An analysis of 493 containers revealed that it took 1 h 52 min on average after the truck entered the terminal until the reefer container was plugged into a power source. Ideally, the plug-in time should be less than 40 min. The study found that 75.8% of containers are not plugged in within 40 min and 15% of containers waited longer than 3 h before they were plugged in. This was caused by 41% of the trucks arriving between 12:00 and 15:00, which overlaps with lunch break and change of shifts, resulting in fewer workers having to handle the peak (Goedhals-Gerber, Stander & Van Dyk 2017).

Valentine and Goedhals-Gerber (2017) studied the influence of logistical activities during the initial 48 h of an apple supply chain on quality and yields. The time of harvest and time of cooling significantly influenced the time until the apples reached their prescribed temperature. The study identified picking at the right time as well as immediate transportation to cooling facilities as vital activities to ensure the fruit quality required for export.

Goedhals-Gerber, Fedeli and Van Dyk (2021) expanded on the trials conducted by Haasbroek (2013). They measured fruit pulp and ambient temperature for 12 containers of pome fruit from packhouses in the Western Cape to the first

DC in the Netherlands. Temperature monitors were inserted in the bottom, middle and top layers of six pallets per container to investigate whether the temperature varies within a pallet. These pallets were loaded at the closed end, in the middle and at the doors of the reefer container to investigate whether the temperature varies along the length of the container. The data from the trials uncovered additional sources of noncompliance with temperature protocols that had not been discovered in previous studies. Surprisingly, the bottom layer of the pallets tended to be the warmest and recorded the biggest fluctuations in temperature. This was attributed to the fact that the pallets were placed on a concrete floor for loading into the container. Although the floor was covered by a roof, it did not provide full shade the whole day, resulting in the floor absorbing heat from the sun and transferring the heat to the bottom layer of the pallets.

Khumalo (2018) investigated temperature breaks in the export cold chain of navel oranges from producers in Citrusdal to the overseas DC in Philadelphia, Pennsylvania, USA. She identified temperature spikes and temperature breaks at various points along the export cold chain. Temperature spikes occurred after the drenching process when the navels were left to dry. The transportation segment from the packhouse to the cold store at the Port of Cape Town also reflected frequent temperature spikes, most likely resulting from poor airflow inside the tautliner. Frequent temperature breaks were detected when the citrus was removed from the cold store and placed in an unrefrigerated area for inspection. Both ambient and pulp temperatures rose during inspection. Significant temperature breaks also occurred during the loading of the vessel for the same reason.

The study, unfortunately, had a low temperature monitor retrieval rate as a result of the negligence of some of the individuals who had to collect them in Philadelphia. As very few temperature breaks occurred during the sea voyage, Khumalo recommended a further investigation of the SA portion of the citrus export cold chain from Citrusdal, which would enable the researcher to personally retrieve the temperature monitoring devices at the Port of Cape Town, and this led to the study discussed in this article.

International studies

This section summarises several previous international studies that are of relevance. These studies highlight the importance of proper cold chain management.

Bremer (2018) proposed an object-oriented reference model to cater for the unique requirements of temperature-sensitive perishable products and the cold chain, thereby filling a gap in the management of cold supply chains. Guo, Wu and Chen (2018) investigated how sociodemographic factors affect decision-makers' perception of risk and choice of risk-mitigation strategies for cold chain management. Ali, Nagalingam and Gurd (2018) argued that there is a need for an integrative approach to cold chain logistics risks and therefore developed a resilience model.

Perishable products that reach a final customer at the required quality signify the cumulative effort made by each stakeholder in the cold chain (Chopra et al. 2017). One way of achieving this is to ensure transparency in food supply chains (Schiefer, Reiche & Deiters 2014). Apart from typical practices along the cold chain, for example, temperature monitoring and reporting and inspection stations, international best practices include the investment in proactive, automated management systems that offer complete traceability of temperature-sensitive products from the point of production to the point of consumption (Ashok, Brison & LeTallec 2017). Developments in technology have the potential to change cold chains significantly in the future (Schiefer et al. 2014) by offering improved monitoring of the cold chain, resulting in real-time data, improved accuracy and efficient reporting systems.

A study carried out in the USA in 2017 showed a link between time and temperature management in food cold chains and temperature abuses, which resulted in an increase in food waste (Mercier et al. 2018:647). The article also examines the advantages of a management system that is founded on 'time-temperature measurements' to reduce food waste, increase food safety and improve forecasts on operating expenses and capital investments (Mercier et al. 2018:663).

Ndraha et al. (2018) reviewed the literature on temperature abuse in food cold chains. They define temperature abuse as 'an unacceptable deviation from the optimal temperature or optimal temperature regime for a given food product for a certain period of time' (Ndraha et al. 2018:13). They identified 86 articles of relevance, of which the first was published in 2001. Temperature abuse was reported for all categories of perishable products and all stages of the cold chain.

It was shown by Nunes et al. (2014) that produce should be precooled as soon as possible after harvesting when it is at its highest temperature, which results in rapid loss of shelf life. James, James and Evans (2006) found that precooling is especially important before transporting produce, as the refrigeration systems used in trucks and shipping containers are unable to reduce the temperature of the load as they are designed to maintain the temperature.

Pelletier et al. (2011) monitored temperature and relative humidity in strawberry shipments from harvest in California to the DC in Florida, USA. Five different precooling treatments were compared. Fruit that had been precooled immediately to 1.7 °C had a better quality upon arrival at the DC than the fruit that had not been precooled immediately or had been precooled to a higher temperature. However, the refrigerated trailer could not maintain the temperature of any of the pallets.

Truck loading and unloading can result in increases above protocol temperatures. Abad et al. (2009) reported an increase of 2.0 °C during the loading of chilled fish in polystyrene boxes into a truck at an airport in Germany and an increase of 3.0 °C during offloading at the destination.

Rediers et al. (2009) tracked temperature in the fresh-cut endive supply chain from the producer to the restaurant in Canada and used it to identify critical points for cold chain management. The effect of temperature on microbial food safety was also analysed.

The effect of temperature, relative humidity and CO_2 levels on the quality of fruit in a fresh peach and nectarine cold chain was investigated by Wang et al. (2017). A wireless sensor network was used for real-time monitoring from the orchard to the retailer in Croatia. Fruit softening was identified as the main problem when temperature is not controlled properly.

Heterogeneity of the temperature inside a pallet and according to the position of the pallets inside a refrigerated container have been reported by a number of authors (Amador, Emond & Nunes 2009; Defraeye et al. 2016; Tanner & Amos 2003). Tanner and Amos (2003) compared shipments of kiwifruit in a refrigerated container and a specialised refrigerated vessel from New Zealand to Belgium. They found significant variability in temperature along the length of the deck of the refrigerated vessel. Although the delivery air temperature of the refrigerated container remained close to the required set point, they found significant differences in temperature between pallet positions as well as between the different levels within a pallet. This is in line with Amador et al. (2009) and Defraeye et al. (2016), who found that the temperature near the bottom of a pallet was 3 °C – 4 °C lower than near the top in a refrigerated pineapple container shipped from Costa Rica to Florida and in refrigerated citrus containers simulating shipment from South Africa to Europe, respectively.

Defraeye et al. (2016) investigated the feasibility of an ambient loading protocol for citrus exports in refrigerated containers from South Africa. Multiple parameters were monitored, including cooling rate, pest disinfestation efficacy, quality and shelf life and energy consumption of the cooling unit. The refrigerated container was able to cool the citrus in approximately three days to the seven-eighths cooling time. More extensive trials are required to test disinfestation efficacy for a variety of pests.

Contribution of the research

The findings of this research provided valuable input for the citrus industry. This research focused on the temperature profile in the SA leg of the citrus export cold chain under cold sterilisation. Prior research on the topic was negatively impacted by a poor retrieval of temperature monitoring devices, impacting the validity of results. However, because the primary researcher in this research placed and collected the temperature monitoring devices used in the trials himself, a retrieval rate of more than 90% of the temperature monitors was achieved, resulting in extensive data for analysis. This research identified temperature variability in each segment of the export chain and determined that the farm segment significantly outperformed the remainder of the export chain. The stages that were worst hit by temperature variability were the transportation segment, the inspection segment during the cold storage stage and the switchover to steri during the cold storage stage. This research allowed the citrus industry to investigate and adjust current cold chain practices internally to prevent temperature variability in future and ultimately prolong the shelf life of the product. Together with the insights of the citrus industry, the integrity of the entire export cold chain could be improved. The improvement of cold chain integrity could lead to possible financial savings, reduction of food waste and potentially a higher quality product with greater revenue generating potential.

Methodology

The study's main objective was to identify temperature breaks during the beginning stages of the cold chain for navel oranges and clementines from Citrusdal in the Western Cape province of South Africa to the Port of Newark, New Jersey, in the USA. This research made use of a deductive approach. A mixed-methods approach was used, as both quantitative and qualitative data were collected and analysed.

Secondary data were collected to assist in the understanding and analysis of key focal areas for this study and created a foundation for the study. Primary qualitative data in the form of observations that were conducted at various stages along the cold chain were analysed. Observations were made at farms where the fruit was harvested, at packhouses, at the cold stores, as well as at the port. In addition, primary data in the form of temperature data were collected along the initial stages of the citrus cold chain. This entailed gathering pulp and ambient temperature data by inserting iButton® temperature monitors into and between the fruit. An iButton® consists of a tiny computer chip enclosed in a small steel can, approximately the size of a watch battery.

The research focused on one specific supply chain and provided an in-depth inquiry into the topic within its real-life setting. Therefore, the research strategy used for this research is a case study (Saunders, Lewis & Thornhill 2016:184). Case study research is the appraisal of a single unit in order to establish its main features and draw generalisations (Bryman 2012). It can offer insights into the specific nature of any example and can determine the significance of culture and context in differences between cases (Silverman 2013).

With the assistance of the Stellenbosch University's Centre for Statistical Consultation, a sample size of 144 temperature monitors was determined. Data were collected for two consignments of clementines and two consignments of navels. Therefore, each consignment contained 36 iButtons®, of which 18 measured pulp temperature and 18 measured ambient temperature. The initial stages of the export cold chain were divided into five segments, namely the outside stage, degreening stage, packhouse and transportation stage, cold storage stage and steri stage.

The researchers inserted the iButtons® on the farm right after the drenching process to record both the waiting period (outside stage) before the degreening process as well as the degreening process. To measure pulp temperature, a small incision was made in the fruit for an iButton® and then covered with tape. To measure ambient temperature, an iButton® was taped to the outside of a fruit. Upon completion of degreening, the farm staff removed the iButtons® from the fruit and kept them aside until they confirmed a packing date with the researchers. On the packing day, the researchers returned to the farm and re-inserted the iButtons® after the fruit had been packed in cartons. The iButtons® could not go over the packing line, as they cannot tolerate the chemical processes on the line and the packing machines would reject the fruit with iButtons® for having defects.

In the packhouse, the farms kept the fruit aside under normal packhouse conditions until a truck arrived to transport the pallets to the cold storage facility at the Port of Cape Town. Six pallets each contained two iButtons® (one measuring pulp and the other ambient temperature) in the bottom cartons, two in the middle cartons and two in the top cartons. The forklift operators were instructed to load these pallets in the front and back of the front tautliner trailer and in the back of the rear trailer. Upon the citrus' arrival at the port, the pallets were unloaded and placed in cold storage until they were moved to the steri chambers for the steri protocol. Shortly before the fruit was loaded onto the reefer vessel, the researchers removed the pieces of fruit with iButtons® from the steri chambers on the quayside.

After all the trials had been completed, the researchers downloaded the data from the iButtons® into Microsoft Excel. Data were successfully retrieved from 130 of the 144 iButton® – 73 457 data points in total. Each consignment's data were organised in a separate spreadsheet and then converted into a format suitable for Tableau, which was used for data visualisation. With Tableau, the researcher constructed time-series line graphs to display the combined temperature maps of each consignment's iButtons®. This made it easy to indicate temperature breaks on the graphs. Furthermore, the researchers used Tableau to construct box-and-whisker plots that illustrate the temperature dispersion of each trial. In addition, the researchers created Excel spreadsheets to analyse the temperature dispersion during the temperature breaks.

Previous research has used a similar methodological approach, and therefore, it can be concluded that this methodology is established and has proven to bring about critical results within the citrus industry.

Variables

The following variables were used for data analysis.

Temperature

This research measured temperature in degrees Celsius (°C). Degrees Celsius conveys the presence or absence of heat.

Date

The dates used in this research identify the day of the month for the 2018 calendar year. This is the year that the data were collected. This research conveys date according to the following configuration: DD/MM/YYYY where D = day, M = month and Y = year.

Time

Time denotes the time of day on a specific date. The iButtons® recorded temperature data every 30 min, that is, twice an hour. This research conveys time as 00:00 or hours:minutes.

Stage

The cold chain is made up of various stages and this research provides results per stage. The stages in this research are the outside stage, degreening stage, packhouse and transportation stage, cold storage stage and steri stage.

Definitions

The following definitions were used for the purpose of this study.

Temperature break

A temperature break in this research is defined as: anytime along the export cold chain that the temperature rises by 2 °C or higher for 90 min or longer.

Temperature spike

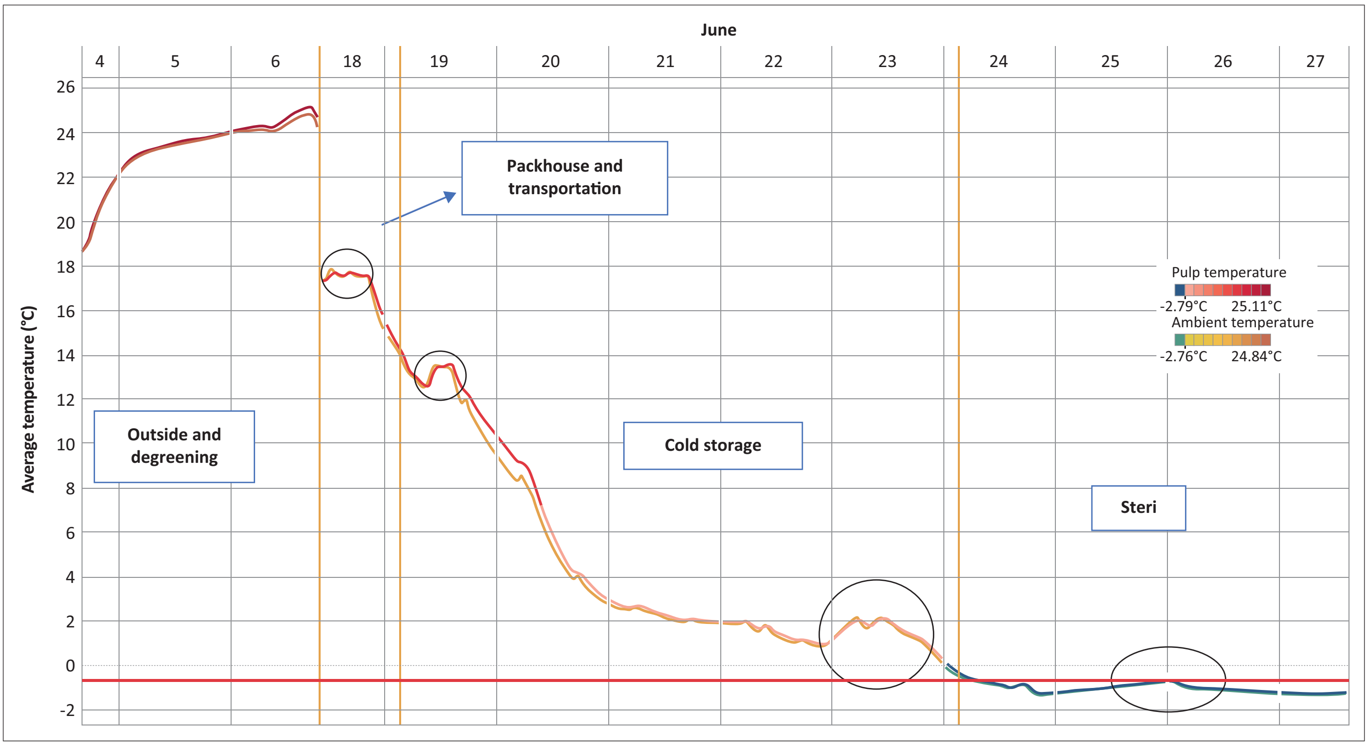
A temperature spike is defined in this research as: anytime the temperature increases along the citrus export cold chain but does not meet all the criteria of a temperature break. In addition, it is used to refer to specific cases. For example, in the degreening stage, the temperature is meant to increase, but not beyond a maximum temperature of 25 °C. If the temperature rises above this level, it is considered a temperature spike.

Chilling injury threat

Citrus fruit is susceptible to chilling injury when the temperature drops to -1.5 °C or below.

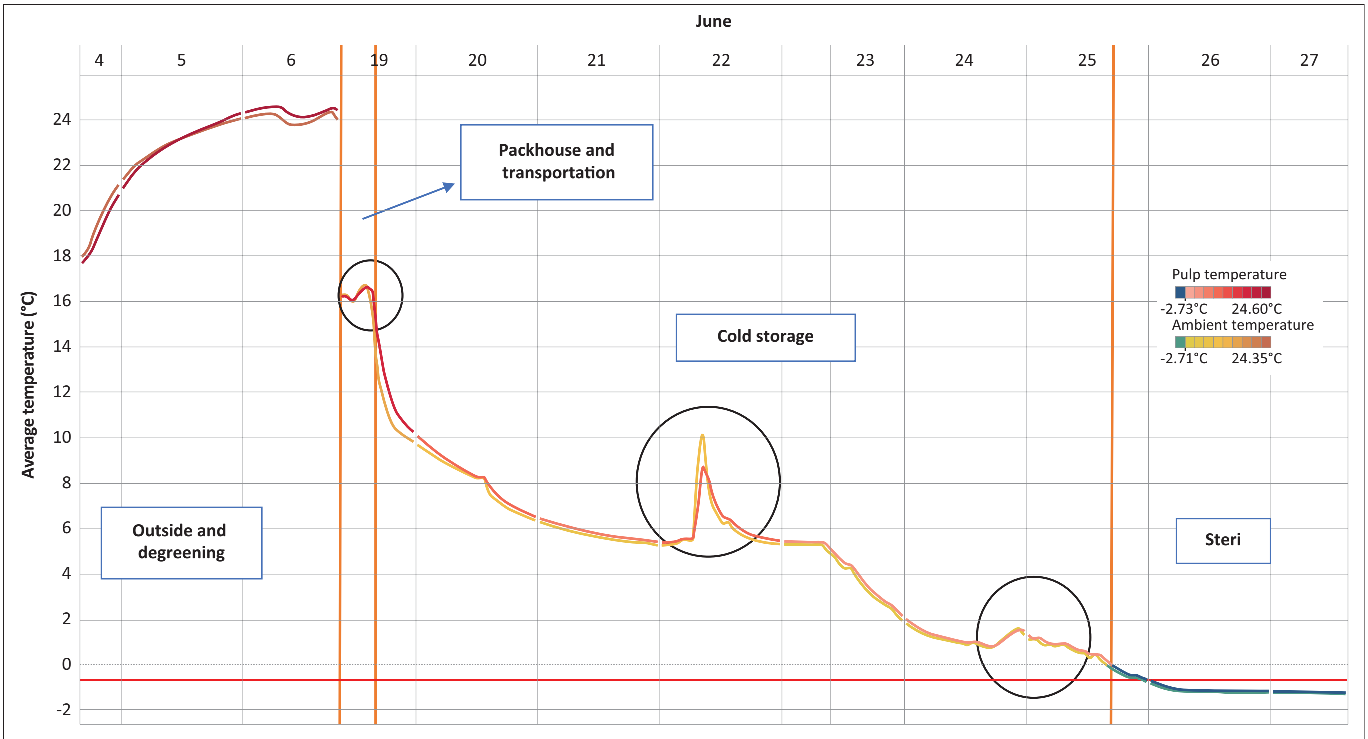
Results

The line graphs of the fruit pulp and ambient temperatures during the various cold chain stages for the four consignments are shown in Figure 5 (clementines load one), Figure 6 (clementines load two), Figure 7 (navels load one) and Figure 8 (navels load two). Each graph depicts the average temperature reading of the 18 iButtons® (pulp temperature) and 18 iButtons® (ambient temperature) at each point in time



Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

FIGURE 5: Time-series line graph of clementines load one: Pulp and ambient temperature.



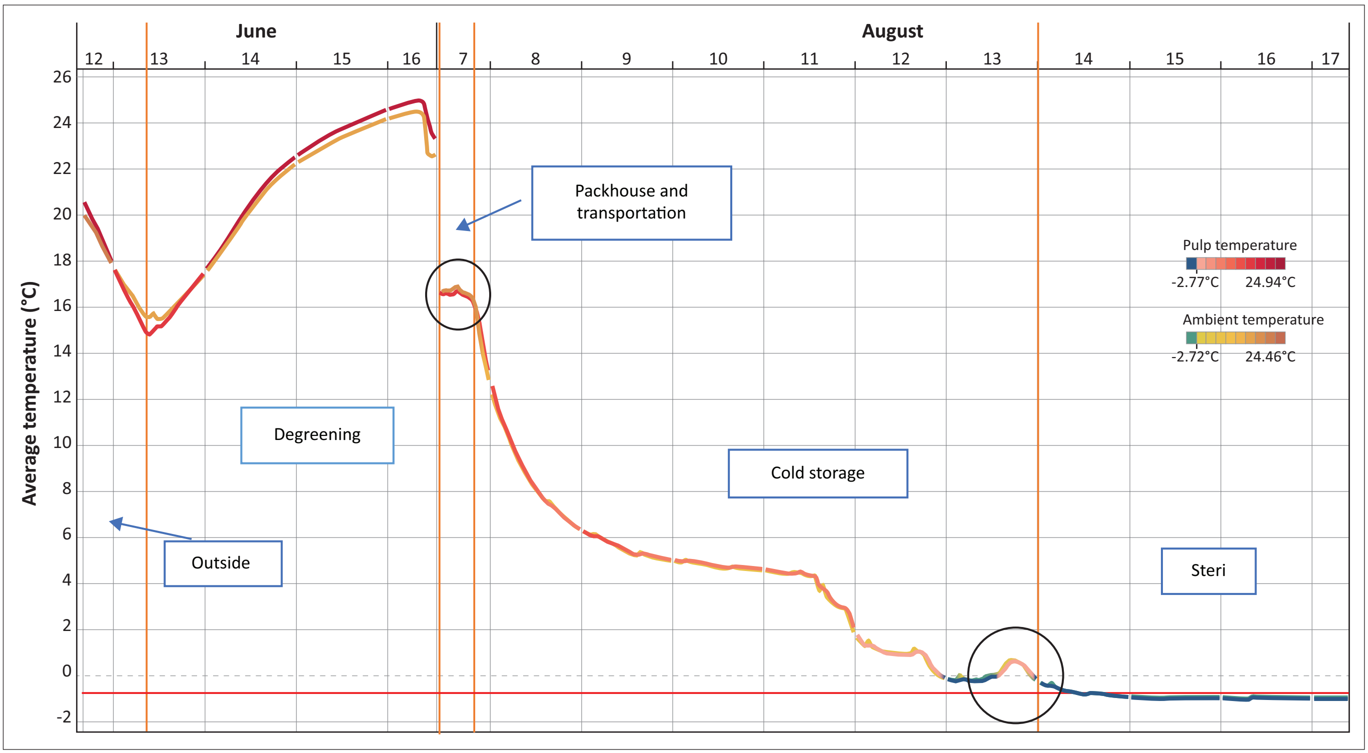
Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

FIGURE 6: Time-series line graph of clementines load two: Pulp and ambient temperature.

in the particular consignment. However, the individual temperature readings were used for data analysis. Vertical orange lines on the time-series line graphs separate the stages from each other. The four consignments are now compared for each of the stages.

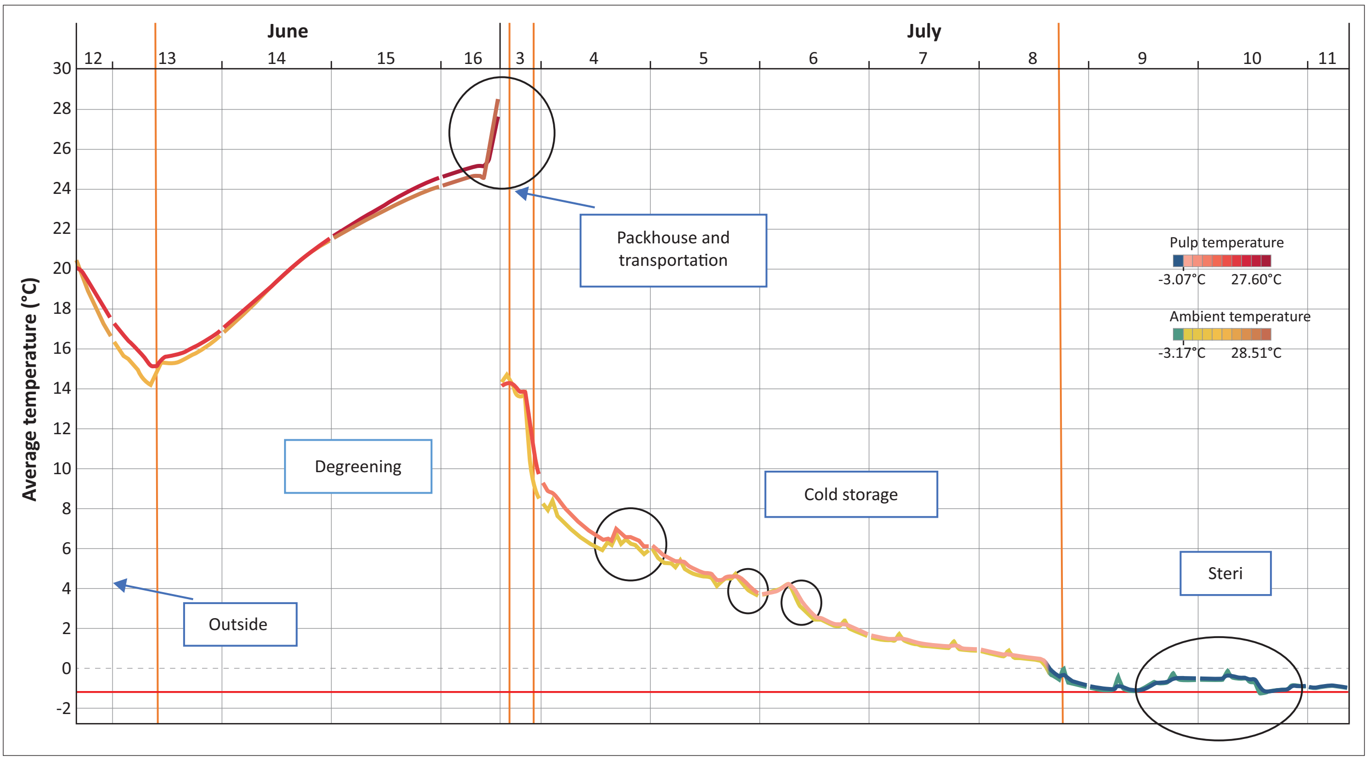
Outside and degreening

The two clementine loads only spent 2 h outside before starting the degreening process. The two navel loads stayed outside overnight – the resulting decrease in pulp and ambient temperature can be seen on Figure 7 and Figure 8.



Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

FIGURE 7: Time-series line graph of navels load one: Pulp and ambient temperature.



Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

FIGURE 8: Time-series line graph of navels load two: Pulp and ambient temperature.

The pulp and ambient temperature rose quite rapidly during the degreening stage as the temperature in the room is set between 20 °C and 25 °C. The temperatures of the first three consignments remained within the allowed range, but there was a significant temperature surge towards the end of the degreening phase of the second navel consignment. According to P. Cronjé (pers. comm., 19 August 2019), degreening may accelerate fruit respiration, which can cause the citrus to heat up uncontrollably. Therefore, some experts oppose the degreening process. Table 1 illustrates the temperature dispersion during the temperature surge.

Packhouse and transport

There were no problems during the packing of any of the consignments. However, each consignment had either a temperature spike or break during the transportation segment. At the beginning of the transport segment of the first clementine consignment, 34 of the 36 iButtons® recorded a temperature spike. In the second clementine consignment, three of the ambient iButtons® recorded a short temperature break, but it did not cause a pulp temperature break. In the first navel consignment, 29 of the iButtons® recorded a temperature spike towards the end of the transport segment. The second navel consignment had a minor temperature spike at the start of the transport segment. The temperature break and spikes resulted from a combination of insufficient airflow inside the tautliner trailers that have no ventilation systems, fruit respiration and climatic conditions. Table 2 illustrates the temperature dispersion during the temperature break and spikes.

Cold storage

A number of temperature breaks and spikes occurred during the cold storage stage. These incidents are discussed separately for each consignment.

As the pallets did not all enter cold storage or steri at the same time, the cold storage stage was defined as follows: from when the first device enters cold storage until the last one reaches the steri-protocol temperature.

TABLE 1: Temperature dispersion of navels load two: Degreening temperature surge.

Variable	Pulp (°C)	Ambient (°C)
Average	25.46	25.33
Median	25.08	24.62
Average increase	4.10	7.06
Median increase	5.06	6.58
Standard deviation	1.82	2.96
Minimum	21.29	21.20
Maximum	35.11	42.86

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

Clementines load one

The temperature decreased to an alarmingly cold level during the cold storage stage, with the lowest ambient temperature missing the chilling injury threshold by 0.01 °C. In addition, there were two temperature breaks.

During the first incident, four monitors (one pulp and three ambient) registered temperature breaks. The temperature breaks most probably occurred while the pallets were moved between cold rooms or while the pallets were removed from cold storage for inspection.

During the second incident, only one ambient monitor qualified as a temperature break. The temperature increased as a result of exposure to climatic temperatures when the citrus was moved from cold storage to the steri chambers.

Clementines load two

One temperature break and one spike occurred during the cold storage stage. The temperature break occurred when the pallets were removed from cold storage for inspection. Thirteen pulp monitors and 14 ambient monitors recorded this break. The most severe pulp temperature increase was 7.52 °C, which is concerning.

The temperature spike occurred near the end of the cold storage stage, when the pallets were moved to the steri chambers. None of the ambient or pulp monitors qualified as temperature breaks.

Table 3 illustrates the temperature dispersion during the temperature spike and breaks of the two clementine consignments.

Navels load one

There were no temperature spikes or temperature breaks during the inspection segment of the cold store stage. However, there was a temperature break during the switchover from cold storage to the steri chambers. Three monitors (two pulp and one ambient) registered a temperature break.

Navels load two

There was a temperature break and two temperature spikes, all affecting ambient as well as pulp temperatures, during the

TABLE 2: Temperature dispersion of consignments: Packhouse and transportation.

Cultivar	Clementines 1: Temp. spike		Clementines 2: Temp. break		Navels 1: Temp. spike		Navels 2: Temp. spike	
	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)
Temp. type								
Average	17.56	17.56	16.26	16.33	16.52	16.65	14.13	14.12
Median	17.71	17.71	16.12	16.22	16.51	16.75	14.26	14.24
Average increase	0.76	0.79	1.16	1.94	0.50	0.75	0.26	0.56
Median increase	0.69	0.75	1.19	1.81	0.31	0.63	0.19	0.44
Standard deviation	0.67	0.79	1.54	1.68	0.88	1.02	0.80	0.98
Minimum	15.20	15.27	13.25	13.45	14.26	13.27	12.14	12.30
Maximum	20.13	20.07	20.16	22.53	18.08	18.47	15.57	16.54

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280
Temp., temperature.

TABLE 3: Temperature dispersion of clementines loads one and two: Cold storage.

Cultivar	Clementines 1: 1st Temp. break		Clementines 1: 2nd temp. break		Clementines 2: Temp. break		Clementines 2: Temp. spike	
	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)
Temp. type								
Average	11.26	10.72	6.12	6.13	6.12	6.13	6.12	6.13
Median	8.20	7.24	5.37	6.24	5.37	6.24	1.07	1.07
Average increase	1.55	1.94	3.83	5.55	3.83	5.55	0.65	0.94
Median increase	1.47	2.23	3.32	5.27	3.32	5.27	0.72	0.94
Standard deviation	2.77	3.08	2.36	2.40	2.36	2.40	0.32	0.36
Minimum	4.93	4.54	3.66	3.79	3.66	3.79	3.66	3.79
Maximum	18.30	18.34	13.26	14.04	13.26	14.04	13.26	14.04

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

Temp., temperature.

TABLE 4: Temperature dispersion of navels loads one and two: Cold storage.

Cultivar	Navels 1: Temp. break		Navels 2: Temp. break		Navels 2: 1st temp. spike		Navels 2: 2nd temp. spike	
	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)
Temp. type								
Average	0.33	0.39	6.42	6.11	4.37	4.24	3.92	3.92
Median	-0.06	0.13	5.86	5.64	4.34	4.25	3.91	3.88
Average increase	1.07	1.17	1.19	1.78	0.74	1.05	0.52	0.70
Median increase	0.82	0.88	1.10	1.98	0.78	1.13	0.56	0.69
Standard deviation	0.50	0.54	1.86	1.58	0.51	0.51	0.21	0.23
Minimum	-0.48	-1.05	3.51	3.52	3.16	2.85	3.47	3.44
Maximum	2.54	3.08	11.76	11.07	6.08	5.65	4.45	4.65

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

Temp., temperature.

cold storage stage. The first temperature spike occurred one day after the temperature break, followed by another temperature spike shortly thereafter. The most probable reason for the temperature break and spikes is either exposure to outside air during inspection or transferral between cold stores during stowage.

The data reflected no temperature breaks or temperature spikes during the switchover from cold storage to steri. Table 4 illustrates the temperature dispersion during temperature breaks and spikes of the two navel consignments.

Steri

A few temperature spikes and chilling injury threats occurred during the steri stage. These incidents are discussed separately for each consignment.

Clementines load one

There was a prolonged temperature spike lasting almost a day during the steri stage. The maximum pulp temperature was -0.16 °C, which is considerably higher than the recommended steri temperature of -0.6 °C. If the temperature increased above 0 °C, the fruit would have to be cooled for another 24 h according to USDA regulations. The minimum pulp temperature -1.78 °C is alarming, as it is below the chilling injury threshold of -1.5 °C.

The temperature spike was most likely a result of operational inefficiencies. The temperature control personnel probably increased the temperature setting as the ambient temperature

TABLE 5: Temperature dispersion of clementines load one and navels load 2: steri.

Cultivar	Clementines 1: Temp. spike		Navels 2: Temp. spike	
	Pulp (°C)	Ambient (°C)	Pulp (°C)	Ambient (°C)
Temp. type				
Average	-0.97	-0.97	-0.62	-0.63
Median	0.73	0.75	-0.61	-0.65
Average increase	0.62	0.74	0.84	1.17
Median increase	0.60	0.72	0.82	1.13
Standard deviation	0.29	0.31	0.31	0.30
Minimum	-1.69	-1.80	-1.37	-1.29
Maximum	-0.16	-0.25	0.20	0.31

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

Temp., temperature.

breached the chilling injury threshold. Table 5 illustrates the temperature dispersion during the temperature spike.

Clementines load two

There were no temperature spikes or breaks. However, the minimum pulp temperature was -1.56 °C, which is below the chilling injury threshold of -1.5 °C.

Navels load one

There were no temperature spikes or breaks, and the temperature never approached the chilling injury threshold.

Navels load two

There was a prolonged temperature spike that continued for most of the steri stage. The maximum pulp and ambient temperatures were 0.20 °C and 0.31 °C, respectively. However, the fruit was not recooled for an additional 24 h as required by USDA regulations. The minimum ambient temperature breached the chilling injury threshold of -1.50 °C but only by 0.01 °C. The temperature spike was most probably caused by poor cold chain management.

Table 5 illustrates the temperature dispersion during the temperature spikes.

Discussion

The results indicate that the outside stages for all four consignments reflected stable temperatures, which imply that the farms implement good cold chain practices. The degreening stages also reflected stable temperatures apart from the temperature surge at the end of the second navel consignment's degreening stage. The increased temperature and CO_2 addition during degreening increase fruit respiration, which could lead to a temperature surge. Some experts therefore oppose the degreening process (P. Cronjé, pers. comm., 19 August 2019). It is recommended that the farms invest in temperature probes to monitor the citrus' temperature during degreening.

Temperatures were stable during the packhouse segment. However, during the transport segment, three of the consignments had temperature spikes, and the fourth one had an ambient temperature break. These incidents result from the combined effect of poor airflow inside the tautliner trailers, fruit respiration and climatic temperatures. It is recommended that exporters and transporters experiment with the possibilities of improving the airflow inside tautliner trailers and that freight planners schedule transportation during cooler times of the day. Alternatively, refrigerated transport could be used, but it is more expensive.

The cold storage stage was the most problematic. Each consignment had at least one temperature break, and three consignments had more than one temperature break and/or spike. Three consignments had temperature breaks when the fruit was removed from the cold storage for inspection in ambient temperature. It is recommended that inspections are conducted in a temperature-controlled room.

In addition, two consignments experienced a temperature break and one a temperature spike when the fruit was transferred from the cold storage to the steri chambers. It is recommended that the transfer process is streamlined through proper planning, training and execution.

The final problem area was the steri stage, during which there were temperature spikes as well as instances of chilling injury threat. Only one consignment did not have any temperature incidents. Two consignments each had a temperature spike, while three consignments each had a chilling injury threshold breach. The research team believes that these issues are inter-related and that they result from poor cold chain practices. Initially, the temperature control personnel allow the temperature in the steri chambers to drop too low, which could result in chilling injury, after which they implement damage control by increasing the temperature, resulting in temperature spikes or breaks that could breach the steri protocol. It is recommended that the temperature monitoring process should be improved, for example, by using more pulp temperature monitors and monitoring the temperature more closely.

TABLE 6: Number of temperature breaks and spikes per stage.

Stage	Temperature break		Temperature spike		Chilling injury threat
	Pulp	Ambient	Pulp	Ambient	Pulp
Degreening	0	0	1	1	0
Packhouse	0	0	0	0	0
Transport	0	1	4	3	0
Cold storage	4	5	4	3	0
Steri	0	0	2	2	3

Source: Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, from http://scholar.sun.ac.za/handle/10019.1/107280

Table 6 summarises the number of temperature breaks and spikes as well as the number of chilling injury threats for the various stages.

Conclusion

Although limited in number, the temperature trials conducted during this study managed to identify the location, frequency, magnitude and duration of temperature breaks and spikes in the SA portion of the export cold chain of clementines and navel oranges from Citrusdal, South Africa, to the Port of Newark, USA. Temperature breaks and/or temperature spikes occurred during degreening, transportation from packhouse to cold store, inspection while in the cold store, transfer from cold store to steri chambers and the steri stage. In addition, there were instances of chilling injury threat during the steri stage.

Further investigation of the frequency and severity of temperature spikes during degreening could shed light on the impact of degreening on fruit quality.

Analysis of the temperature profile inside tautliner trailers for a larger number of trips from the packhouse to the cold store at different times of the day would enable the industry to develop practical solutions for avoiding temperature breaks during this segment of the cold chain.

The cold storage stage was especially problematic, with five ambient and four pulp temperature breaks as well as three ambient and four pulp temperature spikes.

It is essential to reduce the time that citrus spends outside the cold chambers during inspection and transfer, as well as the temperature to which the citrus is exposed during that time, in order to eliminate temperature breaks.

The study endeavoured to recommend possible solutions to the problems identified, which may better protect the quality and prolong the shelf life of citrus exported from Citrusdal. This will benefit the citrus industry and could help to improve their global competitiveness.

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Competing interests

The authors have declared that no competing interest exists.

Authors' contributions

C.A.C. conducted the research as part of his master's degree and co-authored the article. L.L.G.-G. conceived the idea for the research. She acted as the supervisor for the master's research and co-authored the article. F.E.v.D. provided expert input into the master's thesis and co-authored the article.

Ethical considerations

Christoff Conradie, student number 18458386, completed his master's degree in Logistics Management in 2019 at Stellenbosch University. In his research, he collaborated with an organisation that gave him access to physical data that was not linked to individuals or any personal accounts (or information). He was granted access to this data by an authorised representative of the organisation. His study was deemed as low ethical risk by the Departmental Ethics Screening Committee, and he was granted permission to conduct the research for his master's studies (ref. no. LOG-2019-6996).

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Data availability

The data supporting the findings of this research are available on request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

References

Abad, E., Palacio, F., Nuin, M., González De Zárate, A., Juarros, A., Gómez, J.M. & Marco, S., 2009, 'RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain', *Journal of Food Engineering* 93(4), 394–399. https://doi.org/10.1016/j.jfoodeng.2009.02.004

Ali, I., Nagalingam, S. & Gurd, B., 2018, 'A resilience model for cold chain logistics of perishable products', *International Journal of Logistics Management* 29(3), 922–941. https://doi.org/10.1108/IJLM-06-2017-0147

Amador, C., Emond, J.-P. & Nunes, M.C.N., 2009, 'Application of RFID technologies in the temperature mapping of the pineapple supply chain', *Sensing and Instrumentation for Food Quality and Safety* 3, 26–33. https://doi.org/10.1007/s11694-009-9072-6

Ashok, A., Brison, M. & LeTallec, Y., 2017, 'Improving cold chain systems: Challenges and solutions', *Vaccine* 35(17), 2217–2223. https://doi.org/10.1016/j.vaccine.2016.08.045

Bremer, P., 2018, 'Towards a reference model for the cold chain', *International Journal of Logistics Management* 29(3), 822–838. https://doi.org/10.1108/IJLM-02-2017-0052

Bryman, A., 2012, *Social research methods*, 5th edn., Oxford University Press, Oxford.

Chopra, S., Laux, C., Schmidt, E. & Rajan, P., 2017, 'Perception of performance indicators in an agri-food supply chain: A case study of India's public distribution system', *International Journal on Food System Dynamics* 8(2), 130–145. https://doi.org/10.18461/ijfsd.v8i2.824

Citrus Growers' Association, 2018, *Key industry statistics 2018*, viewed 21 April 2022, from http://www.citrusresourcewarehouse.org.za/home/document-home/information/cga-key-industry-statistics/5475-cga-key-industry-statistics-2018/file.

Citrus Growers' Association, 2021, *Key industry statistics 2021*, viewed 21 April 2022, from https://www.citrusresourcewarehouse.org.za/home/document-home/information/cga-key-industry-statistics/7253-cga-key-industry-statistics-2021/file.

Conradie, C.A., 2019, 'Identifying temperature breaks in the initial stages of the cold chain for clementines and navel oranges', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed, n.d., from http://scholar.sun.ac.za/handle/10019.1/107280.

Defraeye, T., Nicolai, B., Kirkman, W., Moore, S., Van Niekerk, S., Verboven, P. et al., 2016, 'Integral performance evaluation of the fresh-produce cold chain: A case study for ambient loading of citrus in refrigerated containers', *Postharvest Biology and Technology* 112, 1–13. https://doi.org/10.1016/j.postharvbio.2015.09.033

Department of Land Reform and Rural Development (DALRRD), 2022, *Overview*, viewed 21 April 2022, from https://nationalgovernment.co.za/units/view/427/department-of-agriculture-land-reform-and-rural-development-dalrrd#:~:text=Department%20of%20Agriculture%2C%20Land%20Reform%20and%20Rural%20Development%20(DALRRD),-Overview%20Management%20Financial&text=The%20Department%20of%20Agriculture%2C%20Land,and%20Land%20Reform%20(DRDLR).

FPEF, 2021, *General information – Fresh produce exporters' forum South Africa*, viewed 21 April 2022, from https://www.fpef.co.za/general-information/.

Freiboth, H.W., 2012, 'Best practice operational procedures for the South African fruit export cold chain from the pack house to the vessel', Unpublished Master's Assignment, Stellenbosch University, Stellenbosch.

Freiboth, H.W., Goedhals-Gerber, L., Van Dyk, F.E. & Dodd, M.C., 2013, 'Investigating temperature breaks in the summer fruit export cold chain: A case study', *Journal of Transport and Supply Chain Management* 7(1), a99. https://doi.org/10.4102/jtscm.v7i1.99

FruitSA, 2020, *Fruit SA statistics 2020*, viewed 21 April 2022, from https://fruitsa.co.za/wp-content/uploads/2021/11/A5-Fruit-SA-Booklet_2021_Web_FINAL.pdf.

Goedhals-Gerber, L.L., Fedeli, S. & Van Dyk, F.E., 2021, 'Analysing temperature protocol deviations in pome fruit export cold chains: A Western Cape case', *Journal of Transport and Supply Chain Management* 15(0), a626. https://doi.org/10.4102/jtscm.v15i0.626

Goedhals-Gerber, L.L., Haasbroek, L, Freiboth, H. & Van Dyk, F.E., 2015, 'An analysis of the influence of logistics activities on the export cold chain of temperature sensitive fruit through the Port of Cape Town', *Journal of Transport and Supply Chain Management* 9(1), Art. #201, 1–9. https://doi.org/10.4102/jtscm.v9i1.201

Goedhals-Gerber, L.L. & Khumalo, G., 2020, 'Identifying temperature breaks in the export cold chain of navel oranges: A Western Cape case', *Food Control* 110, a626. https://doi.org/10.1016/j.foodcont.2019.107013

Goedhals-Gerber, L.L., Stander, C. & Van Dyk, F.E., 2017, 'Maintaining cold chain integrity: Temperature breaks within fruit reefer containers in the Cape Town Container Terminal', *Southern African Business Review* 21, 362–384, viewed 21 April 2022, from https://hdl.handle.net/10520/EJC-c8038f3c1.

Guo, S.-M., Wu, T. & Chen, Y., 2018, 'Over- and under-estimation of risks and counteractive adjustment for cold chain operations: A prospect theory perspective', *International Journal of Logistics Management* 29(3), 902–921. https://doi.org/10.1108/IJLM-02-2017-0047

Haasbroek, L.M., 2013, 'An analysis of temperature breaks in the summer fruit export cold chain from pack house to vessel', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed 21 April 2022, from http://scholar.sun.ac.za/handle/10019.1/85676.

Hordijk, J., 2013, 'Studies to reduce the incidence of chilling injury in Navel orange fruit', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed 21 April 2022, from http://scholar.sun.ac.za/handle/10019.1/80254.

James, S.J., James, C. & Evans, J.A., 2006, 'Modelling of food transportation systems – A review', *International Journal of Refrigeration* 29(6), 947–957. https://doi.org/10.1016/j.ijrefrig.2006.03.017

Kapuya, T., Chinembiri, E.K. & Kalaba, M.W., 2014, 'Identifying strategic markets for South Africa's citrus exports', *Agrekon* 53(1), 124–158. https://doi.org/10.1080/03031853.2014.887908

Khumalo, G., 2018, 'Identifying temperature breaks in the export cold chain of navel oranges: A Western Cape case', Published Master's thesis, Stellenbosch University, Stellenbosch, viewed 21 April 2022, from https://scholar.sun.ac.za/handle/10019.1/103667.

Khumalo, G., Goedhals-Gerber, L., Cronje, P. & Berry, T., 2021, 'The non-conformance of in-transit citrus container shipments to cold protocol markets: A systematic literature review', *Food Control* 125, 107947. https://doi.org/10.1016/j.foodcont.2021.107947

Lafuente, M.T., Zacarías, L., Sala, J.M., Sánchez-Ballesta, M.T., Gosalbes, M.J., Marcos, J.F. et al., 2005, 'Understanding the basis of chilling injury in citrus fruit', *Acta Horticulturae* 682, 831–842. https://doi.org/10.17660/ActaHortic.2005.682.108

Liphadzi, K., 2015, *SA fruit industry: Trends & prospects*, viewed 21 April 2022, from http://3b5dca501ee1e6d8cd7b905f4e1bf723.cdn.ilink247.com/ClientFiles/cga/CitrusGowersAssociation/Company/Documents/CGA-CS_Konanani_Liphadzi_Fruit_SA.pdf.

Mercier, S., Mondor, M., Villeneuve, S. & Marcos, B., 2018, 'The Canadian food cold chain: A legislative, scientific, and prospective overview', *International Journal of Refrigeration* 88, 637–645. https://doi.org/10.1016/j.ijrefrig.2018.01.006

Mogala, M., 2016, *A profile of the South African citrus market value chain*, Department of Agriculture, Forestry & Fisheries, pp. 1–111, viewed 21 April 2022, from https://www.nda.agric.za/doaDev/sideMenu/Marketing/Annual%20Publications/Commodity%20Profiles/field%20crops/Citrus%20market%20value%20chain%202016.pdf.

Ndraha, N., Hsiao, H., Vlajic, J., Yang, M.-F. & Lin, H.-T.V., 2018, 'Time-temperature-abuse in the food cold chain: Review of issues, challenges, and recommendations', *Food Control* 89, 12–21. https://doi.org/10.1016/j.foodcont.2018.01.027

Nunes, M.C.N., Nicometo, M., Emond, J.P., Melis, R.B. & Uysal, I., 2014, 'Improvement in fresh fruit and vegetable logistics quality: Berry logistics field studies', *https://www.researchgate.net/journal/Philosophical-Transactions-of-The-Royal-Society-A-Mathematical-Physical-and-Engineering-Sciences* 372, 20130307. https://doi.org/10.1098/rsta.2013.0307

Pelletier, W., Brecht, J.K., Nunes, M.C.N. & Emond, J.-P., 2011, 'Quality of strawberries shipped by truck from California to Florida as influenced by postharvest temperature management practices', *HortTechnology* 21(4), 482–493. https://doi.org/10.21273/HORTTECH.21.4.482

Perishable Products Export Control Board (PPECB), 2022, *The PPECB: Overview*, viewed 21 April 2022, from https://ppecb.com/about/overview/.

Rediers, H., Claes, M., Peeters, L. & Willems, K.A., 2009, 'Evaluation of the cold chain of fresh-cut endive from farmer to plate', *Postharvest Biology and Technolog* 51(2), 257–262. https://doi.org/10.1016/j.postharvbio.2008.07.017

Saunders, M., Lewis, P. & Thornhill, A., 2016, *Research methods for business students*, 7th edn., Pearson Education Limited, Harlow.

Schiefer, G., Reiche, R. & Deiters, J., 2014, 'Transparency in food networks – Where to go', *International Journal on Food System Dynamics* 4(4), 283–293.

Silverman, D., 2013, *Doing qualitative research: A practical handbook*, Sage, London.

Stander, C., 2014, 'The handling of fruit reefer containers in the Cape Town Container Terminal', Published Master's thesis, Stellenbosch University, Stellenbosch.

Tanner, D.J. & Amos, N.D., 2003, 'Temperature variability during shipment of fresh produce', *Acta Hortic* 599, 193–203. https://doi.org/10.17660/ActaHortic.2003.599.22

Thompson, J.F., 2008, *Commercial cooling of fruits, vegetables, and flowers*, rev. edn., University of California, Oakland, CA.

United States Department of Agriculture (USDA), 2020, *Citrus annual: Republic of South Africa*, viewed 21 April 2022, from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Citrus%20Annual_Pretoria_South%20Africa%20-%20Republic%20of_12-15-2020.

United States Department of Agriculture (USDA), 2021, *USDA: Plant health import information*, viewed 21 April 2022, from https://www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information.

USDA Treatment Manual, 2018, *United States Department of Agriculture*, viewed 21 April 2022, from http://aphis.usda.gov.

Uys, G., 2016, 'Growing South Africa's global fruit exports', *Farmer's Weekly* 16018, 6–7, viewed 21 April 2022, from https://www.farmersweekly.co.za/opinion/by-invitation/growing-south-africas-global-fruit-exports/.

Valentine, A.G.D.T. & Goedhals-Gerber, L., 2017, 'The temperature profile of an apple supply chain: A case study of the Ceres district', *Journal of Transport and Supply Chain Management* 11, 1–8. https://doi.org/10.4102/jtscm.v11.263

Wang, X., Matetić, M., Zhou, H., Zhang, X., & Jemrić, T., 2017, 'Postharvest quality monitoring and variance analysis of peach and nectarine cold chain with multisensors technology', *Applied Sciences* 7(2), 133. https://doi.org/10.3390/app7020133

Zwierzycki, W., Bieńczak, K., Bieńczak, M., Stachowiak, A., Tyczewski, P. & Rochatka, T., 2011, 'Thermal damage to the load in cold chain transport', *Procedia – Social and Behavioral Sciences* 20, 761–766. https://doi.org/10.1016/j.sbspro.2011.08.084