Identifying Temperature Breaks in the Initial Stages of the Cold Chain for Clementines and Navel Oranges: A Western Cape Case

by

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DECLARATION

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

South Africa is the second largest exporter of citrus fruits in the world, with only Spain exporting higher volumes. It is the country's third most exported horticultural product after deciduous fruits and vegetables. It is a growing industry, not only globally, but in South Africa as well. However, the industry, including the Citrusdal region, is concerned that South Africa loses a considerable amount of fresh fruit each year as a result of breaks in the cold chain. Citrus exports from Citrusdal to the USA are susceptible to temperature breaks because exporters predominantly use conventional vessels to ship the fruit and, therefore, the cold chain consists of various role players.

Company J proposed this study, which was a case approach that attempted to identify the prominence, location and causes of temperature breaks along the initial stages of the export cold chain of Clementines and Navel oranges from Citrusdal in the Western Cape of South Africa to the Port of Newark in New Jersey, USA. The study then attempted to provide solutions to the problems that caused the temperature breaks. A power analysis determined a sample size of 144 temperature devices, distributed over two cultivars. Thus, the researcher determined, by means of judgement sampling (mainly influenced by seasonality and availability), to conduct the research on Clementines and Navel oranges.

After collecting the data, the researcher combined each individual device's temperature data into a single Excel file per consignment (there were four consignments in total), after which the researcher utilised Tableau® to construct time-series line graphs and box-and-whisker plots that visually depicted individual temperature breaks during the export cold chain. Furthermore, the researcher used Excel's "tables" function to construct tables of dispersion that illustrated the severity of the temperature breaks. The data analysis identified temperature spikes and temperature breaks in each segment of the export chain and discovered that the farm segment significantly outperformed the post-farm segment. There were consistent temperature breaks / temperature spikes during the transportation segment, inspection segment during the cold storage stage, and switchover to Steri during the cold storage stage.

The findings indicated that the industry's concern regarding fruit loss, as a result of temperature breaks, is grounded and that temperature breaks are prominent during the export cold chains of Clementines and Navel oranges from Citrusdal to the Port of Newark. In an increasingly competitive global citrus market, it is important for producers in the Citrusdal region to address the issues that the study identified, in order to remain competitive and continue producing the high-quality citrus for which the region is known. The recommendations chapter provides possible solutions to the problems that the study identified and emphasises

that avoidable temperature breaks should be eliminated, and unavoidable temperature breaks should be minimised.

Keywords: citrus; cold chain logistics; cold chain stabilization; temperature break; Steri protocol

OPSOMMING

Suid-Afrika is die tweede grootste uitvoerder van sitrusvrugte in die Wêreld, dit word slegs deur Spanje oortref. Dit is die land se derde mees uitgevoerde hortologiese produk, na bladwisselende vrugte en groente. Dit is wêreldwyd, sowel as in Suid-Afrika, 'n groeiende bedryf. Die Suid-Afrikaanse bedryf, insluitend die Citrusdalstreek, is bekommmerd dat 'n aansienlike hoeveelheid vars vrugte elke jaar verlore gaan as gevolg van breke in die koue ketting. Uitvoersitrus vanaf die Citrusdalstreek na die VSA is vatbaar vir breke in die koue ketting omdat uitvoerders grootlik konvensionele verskeping gebruik om die vrugte uit te voer en, sodoende, 'n koue ketting veroorsaak wat uit verskeie rolspelers bestaan.

Maatskappy J het hierdie studie voorgestel. Die studie het 'n geval-benadering gevolg wat beoog het om die prominensie, posisie en oorsake van temperatuur breke gedurende die aanvanklike stadiums van die uitvoer koue ketting van Clementines en Navel lemone vanaf Citrusdal in die Wes-Kaap van Suid-Afrika tot in die Newark hawe, New Jersey in die VSA, te identifiseer. Daarna maak die studie voorstelle om die probleme wat die temperatuur breke veroorsaak op te los. 'n Kraganalise het 'n steekproefgrootte van 144 temperatuur toestelle, versprei oor twee kultivars, bepaal. Deur die gebruik van oordeelsteekproefneming (hoofsaaklik beïnvloed deur seisoenaliteit en beskikbaarheid) het die navorser op Clementines en Navel lemoene besluit.

Nadat die data ingesamel is, het die navorser elke individuele toestel se temperatuur data kombineer in 'n enkele Excel sigblad per besending. Daar was vier besendings in totaal. Daarna het die navorser Tableau gebruik om tydsreeks-lyngrafieke en "mond-en-snor" diagramme op te stel, met die doel om die data grafies te illustreer. Verder het die navorser Excel se "tabelle" funksie gebruik om tabelle van verspreiding op te stel wat die erns van die temperatuur breke illustreer het. Die data-analise het temperatuur breke en temperatuur stygings tydens elke segment van die uitvoer koue ketting identifiseer en het bepaal dat die plaassegment aansienlik beter vaar as die post-plaassegment. Daar was konstante temperatuur breke/ temperatuur stygings gedurende die vervoer segment, inspeksie segment van die koelstoorfase en oorskakeling vanaf die koelstoor na die Sterikamers.

Die bevindinge het aangedui dat die bedryf se kommer oor die verlies van vrugte, as gevolg van breke in die koue ketting, gegrond is en dat daar prominente temperatuur breke gedurende die uitvoer koue kettings van Clementines en Navel lemoene vanaf Citrusdal tot by die Newark hawe is. In 'n globale mark wat toenemend kompeterend is, is dit belangrik vir produsente in die Citrusdalstreek om die kwessies wat hierdie studie identifiseer het aan te spreek, sodat hul kompeterend kan bly en aanhou om die hoë kwaliteit sitrus te lewer waarvoor die streek bekend is. Die voorstelle-hoofstuk verskraf moontlike oplossings vir die probleme wat die studie identifiseer het en beklemtoon dat voorkombare temperatuur breke elimineer moet word, terwyl onvoorkombare temperatuur breke minimeer moet word.

Sleutelwoorde: sitrus; koue ketting logistiek; koue ketting stabilisering; temperatuur breek; Steri protokol

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Refrigerated transportation faces unique challenges that other modes of transport do not regularly face (Zwierzycki, Bieńczak, Bieńczak, Stachowiak, Tyczewski & Rochatka, 2011). Post-harvest cold chain maintenance is a critical factor for ensuring high quality citrus that meet export standards (Defraeye, Nicolai, Kirkman, Moore, Niekerk, Verboven & Cronjé, 2016) and temperature stabilization is one of the most prominent challenges in the export chain of fresh fruit (Zwierzycki *et al.*, 2011). Furthermore, Freiboth, Goedhals-Gerber, Van Dyk & Dodd (2013) state that the industry is concerned about the substantial amounts of produce that go to waste each season as a result of breaks in the cold chain.

South Africa's horticultural sector is the largest contributor to the country's agricultural exports. Ninety percent (90%) of the income generated by the horticultural sector comes from exports and amounts to approximately R22 billion annually (Steenkamp, 2016). Citrus are South Africa's third most exported product, exceeded only by deciduous fruits and vegetables. Therefore, it as an important industry for the country (Mogala, 2016).

This study addresses the cold chain stabilization problem that the industry faces by identifying temperature breaks in the initial stages of the export cold chain (sometimes referred to as the South African leg of the export cold chain) for Clementines and Navel oranges.

Company J, a citrus exporter that has significant interest in the influence of temperature breaks on citrus' quality, proposed the initial study conducted by Khumalo (2018). Khumalo (2018) identified that although the sea leg of the export cold chain is properly maintained, temperature breaks occur in the initial stages of the export cold chain from SA to the Port of Newark, New Jersey. Unfortunately, Khumalo (2018) experienced problems with device retrieval while undertaking the study and only retrieved half of the devices that were sent to Newark. Therefore, this study aimed to eliminate that problem by only covering the SA leg of the export chain, which enabled personal device retrieval.

Farm A and Farm B harvest, degreen and pack the citrus in Citrusdal in the Western Cape. They then use tautliner trailers to transport the fruit to Company K at the Port of Cape Town, who are responsible for cold storage and the Steri protocol. From there, Company K transports the citrus to the Port of Newark, New Jersey in the United States of America (USA) in conventional vessels. This study only covered the stages up to the Steri protocol, after which the researcher removed the probes.

The study attempted to identify temperature breaks by measuring the pulp and ambient temperatures of the citrus, by using temperature monitoring devices that Company J supplied. These devices are called iButtons®. Furthermore, the study examined the influence of cold chain temperature breaks on citrus quality by conducting a literature review.

1.2 PROBLEM STATEMENT

Industry experts are concerned that a substantial amount of produce goes to waste each year as a result of temperature breaks and poor cold chain maintenance (Freiboth *et al.*, 2013). These temperature breaks have negative effects on citrus quality and shortens the shelf life of the fruit, thereby decreasing SA's international competitiveness. This study aimed to identify these temperature breaks and their prominence. It also aimed to identify the main problem areas as well as whether the temperature breaks are avoidable or unavoidable. Furthermore, after the data analysis, it provides possible solutions to the problems the role players in the cold chain experience. The study emphasises the negative influence of temperature breaks on citrus quality by reviewing and summarizing the available literature to date.

1.3 OBJECTIVES

The list below states the main objectives of the study:

1. Identify temperature breaks in the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey.
2. Identify where temperature breaks occur during the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey.
3. Identify the prominence of these temperature breaks (duration and severity).
4. Identify the causes of these temperature breaks.
5. Identify whether these temperature breaks are avoidable or unavoidable.
6. Analyse the effect that temperature breaks have on citrus quality by reviewing the existing literature.
7. Provide possible solutions to reduce unavoidable temperature breaks, and if possible, eliminate avoidable temperature breaks.

1.4 RESEARCH QUESTIONS

The thesis answers the following research questions:

1. Do temperature breaks occur along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?
2. Where do temperature breaks occur along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?

3. What are the severity and duration of these temperature breaks?
4. Are these temperature breaks avoidable or unavoidable?
5. Why are temperature breaks occurring along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?
6. Do these temperature breaks have a negative impact on the quality of the citrus?
7. How can the various role players in the export cold chain possibly minimise or eliminate these temperature breaks and their influence?

1.5 AIM AND PURPOSE OF THE STUDY

Section 1.1 mentions the industry's concern regarding its considerable losses each year as a result of breaks in the cold chain. This research aimed to identify temperature breaks in the initial stages of the cold chain of Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey. Furthermore, the study aimed to identify where and how often these temperature breaks occur along the export cold chain, as well their severity. In addition, the literature review summarizes various previous studies that confirms the negative effect of temperature breaks on the quality of, especially, citrus fruits, but also fruit quality in general.

After identifying their occurrence, location, frequency and severity, the study aimed to determine what caused the temperature breaks. Determining the causes enabled the formulation of possible solutions that may help producers and exporters from Citrusdal to improve their competitiveness. By eliminating avoidable temperature breaks and minimising unavoidable temperature breaks, the South African industry may gain a competitive advantage through increased quality and prolonged shelf life. Therefore, the purpose of the study was to help improve SA's global competitiveness by identifying temperature breaks and their causes and, thereafter, to provide possible solutions to the problems that cause temperature breaks.

1.6 LAYOUT OF CONTENTS

Chapter 1 is an introductory chapter that provides the background of the study and states the main problem. Furthermore, it identifies the study's objectives and research questions and explains the aim and purpose of the study.

Chapter 2 is a literature review that summarises previous studies from the field and explains the direct link between temperature and fruit quality.

Chapter 3, research design and methodology, explains the study's research approach. The chapter explains the planning process and ethical considerations of the study. Furthermore, it provides important information regarding sampling, data collection and the data analysis.

Chapter 4, the data analysis, analyses the temperature data and graphically depicts the results per cultivar and consignment.

Chapter 5, the interpretation chapter, interprets the results in the data analysis by identifying its main findings and determining the main problems and their causes.

Chapter 6, conclusions, recommendations and future work, determines whether the research has reached its objectives and answered the research questions. It provides possible solutions to the problems that the study identified and proposes possible topics for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This literature review elaborates on the themes that underpin the study by investigating the accumulated knowledge from previous research. In this study, all themes and sub-themes are interrelated; therefore, it is important to inform readers beforehand, so that they understand the results and their implications.

The literature review assisted the researcher in gaining insight regarding the topic. The sections are as follows: 1.1 Introduction, which provides background to where this study fits into the field of supply chain management. Section 1.2, Cold chain logistics, explains the specific logistical sub-division under which the study falls. Section 1.3, The South African fruit industry, informs readers on the diversity of fruit agriculture in South Africa. Section 1.4, The South African citrus industry, explains the significance of the citrus industry in the country. Section 1.5, Citrus and temperature, elaborates on the influence that high and low temperatures have on the quality of citrus fruit while 1.6, Special protocol for citrus exported to the USA, further elaborates on the specific temperature requirements regarding citrus for this study.

In addition, Section 1.7, Citrus quality, describes the various factors that have an influence on citrus quality and how they are measured. Section 1.8, Pests, diseases and defects, is about specific threats to citrus quality and yield size. Section, 1.9 Regulatory organisations, identifies the various role players regarding legislation in the industry while section 1.10, Previous studies, gives an overview of similar research from the past. Section 1.11, Conclusion, ends off the literature review by summarizing some of the important takeaways from the chapter.

2.1.1 WHAT IS SUPPLY CHAIN MANAGEMENT (SCM)?

As the world changed over time, the SCM profession adapted to these changes. Because of this, the definition of SCM has changed on various occasions, and will probably continue changing (CSCMP Supply Chain Management Definitions and Glossary, 2018). The current definition, according to the Council of SCM Professionals (CSCMP), is stated as follows: “SCM encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, SCM integrates supply and demand management within and across companies” (CSCMP Supply Chain Management Definitions and Glossary, 2018).

SCM consists of a broad spectrum of activities and each of these activities are important to the process, if one of them performs inefficiently, the whole supply chain (SC) becomes less efficient. A chain is only as strong as the weakest link (Rouse, 2017). The SCM process can be expansive and consist of various role players. These role players need to collaborate with each other and constantly communicate to ensure that the SC runs as seamlessly as possible (Rouse, 2017). Because of its expansiveness, SC's are reliant on change management and risk management to ensure that the participants in the chain are properly aligned (Rouse, 2017). Proper SCM can be a major benefit for companies, as it enables them to create efficiencies (like economies of scale), increase profit margins and lower costs (Rouse, 2017). Companies can optimize demand management, become better at inventory management, deal better with unforeseen circumstances and offer better service to their customers through SCM (Rouse, 2017).

Figure 1 is a diagram of a very basic SC, which consists of raw materials, a supplier, a manufacturer, a distributor, customers (retailers) and consumers (end-users). It is important to bear in mind that SC's can become quite complex, but most of them have a similar basic structure like the one in the figure.

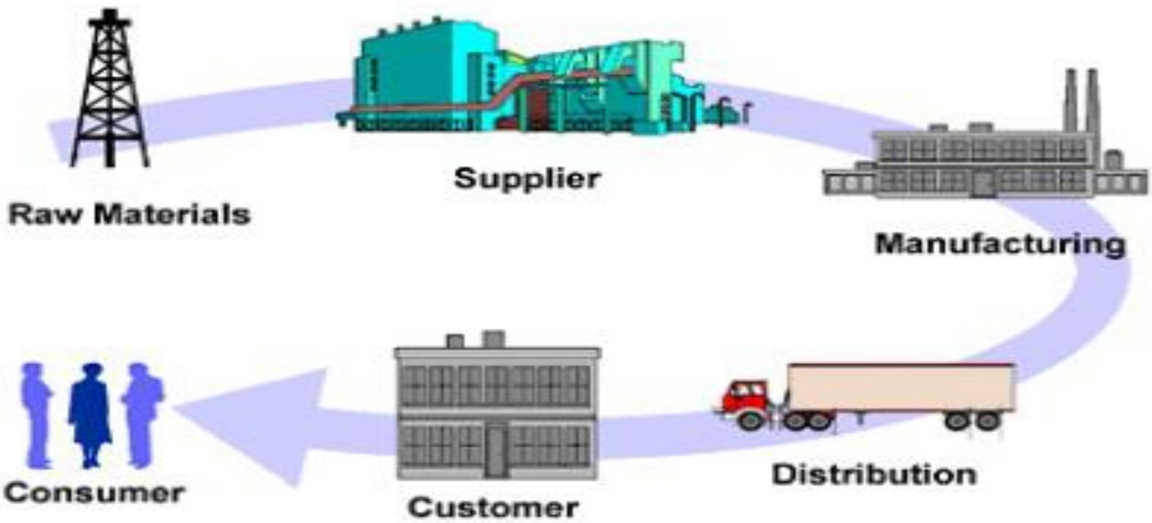

Figure 1: A basic SC

Source: Various stages of supply chain management (2014)

2.1.2 LOGISTICS VERSUS SCM

Logistics and SCM share many similarities, because logistics is a sub-field of SCM. Logistics can be referred to as a component of SCM (CSCMP Supply Chain Management Definitions and Glossary, 2018). Logistics focusses more on the movement of the products, or the components that a product consists of. It aims to ensure that companies optimise the four P's (product, place, price, promotion) of business, by having products or services in the right place, at the right time, in the correct quantities and at the best price (Rouse, 2017). Packaging, transportation, warehousing, distribution and delivery are all logistical activities (Rouse, 2017). SCM however, is more expansive and complex than logistics, as it consists of a broader range of activities that include logistics. A few of these activities that are included in SCM are strategic sourcing, procurement, and coordination of SC visibility (CSCMP Supply Chain Management Definitions and Glossary, 2018).

2.1.3 TYPES OF SUPPLY CHAINS

SC professionals have identified different types of SC's. A company choses a SC strategy that best suits its situation (Meyr & Stadtler, 2008). The citrus industry falls under SCM, because the farmers produce fruits that they sell to the market. The market, in return, has a need for these fruits and buys them from the farmer. This section discusses the four main types of supply chains:

1. The first type of SC is the Make-to-Stock Model. It focusses on post-production inventory build-up and supplies customers from the finished goods inventory according to a sales forecast (Jacobs & Chase, 2014) The model's focus is on tracking what the demand for a product is in real time. This enables production facilities to supply the market with a product at the right time. An integrated IT system is a tool that companies often use to achieve this goal (Meyr & Stadtler, 2008).

   Logistical integration and supplier support that ensure the timely and efficient delivery of components are important elements to this structure's success. Therefore, it requires an efficient forecasting program (Olhager & Prajogo, 2012). Businesses involved in industries that allow for economies of scale like food (perishables), mass customized products, fashion, and fast-moving goods often utilise Make-to-Stock Models (Islam, Fabian Meier, Aditjandra, Zunder & Pace, 2013). Citrus supply chains fall into this category.

2. Companies that want to minimise inventory-carrying costs use the Build-to-Order Model. The model revolves around the idea of waiting for an order before assembling the product. An important technique that manufacturers use to optimise this model is using the same components for a number of products in a production line (Meyr & Stadtler, 2008).

3. The third SC model is the Continuous Replenishment Model. Continuous replenishment is designed around the idea of constantly replenishing inventory on a consistent basis as it is needed (Meyr & Stadtler, 2008),

4. The Channel Assembly Model is the final SC model. It is a modified version of the Build-to-Order Model. This system functions by gathering components as a product makes its way through the SC. The key to making the Channel Assembly Model work is efficiently collaborating with third party logistics providers (3PL's) (Meyr & Stadtler, 2008).

2.1.4 FRUIT SUPPLY CHAINS

Fresh fruit SC's, like the one that this study focusses on, can be difficult to run, as they usually have long lead times, unstable supply and demand figures and small profit margins (Soto-Silva, Nadal-Roig, González-Araya & Pla-Aragones, 2016). The fast handling -and seasonal nature of the fruit industry as well as the fact that many fruit types are highly perishable adds to its complexity and the need for efficient SCM (Soto-Silva *et al.*, 2016). In addition, the fruit industry is competitive and changes constantly, it is also plagued by various risks such as diseases, climate change and fruit biology (Soto-Silva *et al.*, 2016).

2.1.4.1 South Africa's Performance

Mashabela (2007) states that South Africa's (SA's) performance regarding fruit SC's is poor in comparison to its competitors and that the country is struggling to stay up to date, maintaining a marginal comparative advantage globally. On the other hand, Chile, one of SA's major competitors in the fruit industry, is outperforming it significantly. This means that there may be a considerable amount of value-adding opportunities in South African fruit SC's, which are not yet being utilised (Mashabela, 2007). There may be a possibility for this study to identify some of these opportunities.

2.1.4.2 Infrastructure

The fresh fruit export industry consists of a multitude of infrastructure, namely regional pack houses, regional cold stores, cold stores at the port cities (including harbours and airports) and terminals at the port used to export the fruit (Ortmann, 2005). Infrastructure plays an important role in SA's attempt to shift from a developing country to a developed country. Although it is one of the most developed African countries, it is still considered as developing when compared to North American and European countries (Ortmann, 2005). For South African agriculture, infrastructure is vitally important, as it is a strong contributor to the efficient flow of produce through the SC (Ortmann, 2005). For farmers to take advantage of the exchange rate and higher prices offered by the foreign market, they need to minimise the cost of exporting fruit. Infrastructure plays a substantial role in this cost reduction (Ortmann, 2005).

2.1.5 CITRUS SUPPLY CHAINS

The citrus SC starts at the growing phase, during which the fruit undergoes various developing stages. In each stage the trees and fruit require specific treatments to protect them from pests, weeds and diseases (Ortmann, 2005). Weeds are a threat to fruit quality, because they use the same nutrients as the citrus to grow. This prevents the fruit from growing to their full potential. Pests and insects feed on citrus and infest them with eggs, leading to fruit loss and failed inspections (Ortmann, 2005).

When the citrus have developed to their optimal level of ripeness, harvesting starts. The decision to start harvesting is made by the farmer, who determines the ripeness of the fruit by means of visual inspection and previous experience (Ortmann, 2005). Farms utilise a process called 'selective picking' to harvest citrus fruit, which means that not all the fruit on a tree are harvested at the same time. They harvest one tree numerously in a season, because the fruit ripens sporadically.

The most common technique for picking citrus is by hand, using a clipper to remove the fruit from the tree. Groups of workers move through the orchards and place the citrus into picking bags. When the bags reach maximum capacity, the workers empty them into bins nearby. After being picked, they are transported to the packing facility using small vehicles – mostly trailers that are pulled by tractors (Ortmann, 2005). It is best practice to send them through the drenching process as soon as possible. This is done firstly, to protect the citrus against pests and diseases like green mould and secondly, to remove field heat (Erasmus, Lennox, Njombolwana, Lesar & Fourie, 2015). Sections 1.5 and 1.8 discuss drenching in more detail.

Citrus are ready for consumption while the peel is still green, but this state is not acceptable for the market, as customers prefer them to have turned orange before buying them. The degreening stage in the SC accelerates and enhances the orange colour. In this stage, farms place the citrus in a room at a temperature ranging between 20 ºC and 25 ºC, depending on the cultivar. The atmosphere inside the room is filled with Carbon dioxide (CO_2) to speed up the degreening process (Erasmus *et al.*, 2015).

The next stage in the citrus SC is in the pack house. Here, they pack the citrus into boxes by combining man and machine power. The boxes are stacked onto pallets, which are loaded onto tautliner trailers. Trucks transport the fruit to the port where they are stowed in cold rooms at Company K, which specializes in citrus exports. In these rooms, the citrus are force-cooled for 72 hours. This happens in adherence to the USA's Steri protocols. From the cold stores, the pallets are loaded onto a ship, moored at the quayside.

Most South African citrus fruit that are exported to the USA undergo the abovementioned process, because they are transported by means of conventional vessel (Khumalo, 2018). These vessels vary in size and can typically carry between 3500 and 5600 pallets under the hatch, a small number of containers can also be carried on the deck of the ship (Ortmann, 2005). The consumer is the final link in the citrus SC (Zwierzycki *et al.*, 2011). Figure 2 is a diagram of a typical citrus export SC from Citrusdal to the USA. This study only covers the parts that are coloured orange:

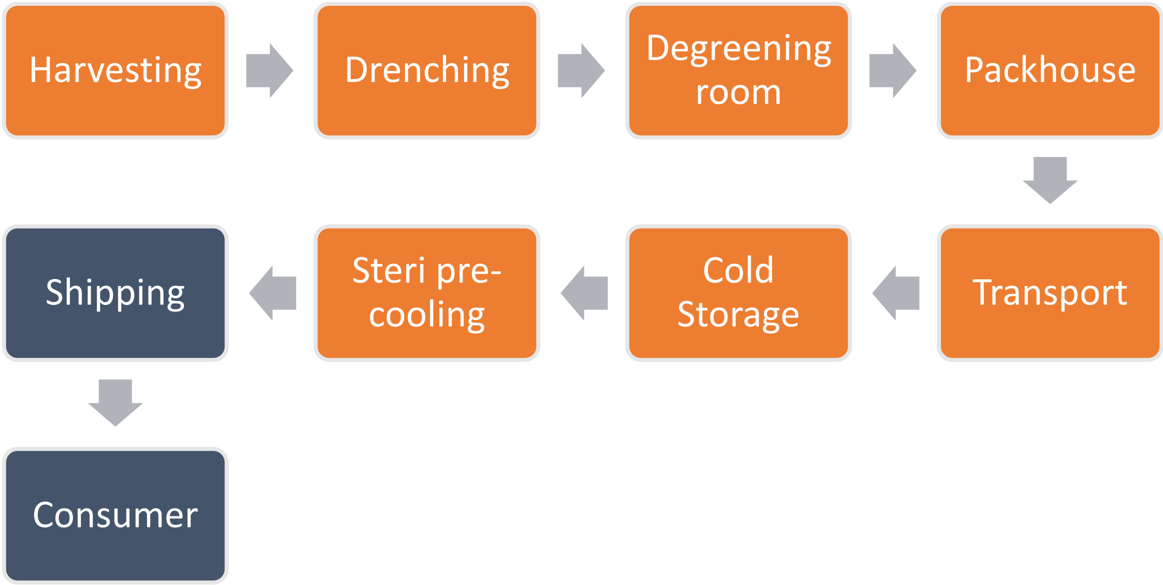

Figure 2: A typical citrus export cold chain

Source: Adapted from Freiboth, Goedhals-Gerber, Van Dyk, & Dodd (2013)

2.2 COLD CHAIN LOGISTICS

Cold chain logistics found its origin in 1940, when Frederick McKinley Jones built the first refrigeration unit that could operate while a truck was in transit (Frederick Jones Biography, 2018). Because of citrus' temperature-controlled transportation nature, this study falls under the field of "cold chain logistics."

The cold chain is a branch of SCM that is used to handle products that may perish quickly in normal temperatures (Zhang & Lam, 2018). Refrigerated transport has managed to continue expanding, despite growing global economic and political concerns. This is mainly because customers' buying power is growing and people are becoming increasingly health conscious (Zhang & Lam, 2018). In 2014, global refrigerated trade had reached 190 million tonnes (Zhang & Lam, 2018). Peoples' demand for different kinds of frozen and refrigerated food is constantly growing, and therefore, the demand for cold chain logistics is constantly growing as well (Li, Wang & Chen, 2012).

Temperature and climate have a definite influence on the quality and lifespan of citrus fruit (Liu, Wang, Liu, Li, Zhang, Tao, Xie, Pan & Chen, 2014), so having an effective cold chain is beneficial for both farmers and exporters, who have to sell the citrus to an overseas market with strict standards. An effective cold chain, however, is something that presents the logistics industry with various challenges, with temperature stabilization being the most prominent (Zwierzycki *et al.*, 2011). Transportation forms a large part of the cold chain, and neglecting proper transport practices could damage the load as well as impose health risks to consumers (Zwierzycki *et al.*, 2011).

Cold chain logistics expands beyond refrigerated transport and comprises of a series of complex tasks like packing, transport, information technology and storage – this makes it a niche market (Li *et al.*, 2012). Vehicle selection, fleet management, infrastructure planning and construction, as well as quality control are more complex for cold chain logistics, because the industry is specialized and often situation specific. In most cases, it is more expensive than normal logistics, as it requires unique infrastructure, machinery and technology. The staff that operate and manage the tools and systems used in cold chain logistics must often undergo special training, which leads to additional costs. Some of these costs are not required for other logistical modes (Zwierzycki *et al.*, 2011).

2.3 THE SOUTH AFRICAN FRUIT INDUSTRY

SA utilises an economic growth strategy that is export driven, meaning that the country is in pursuit of a higher export figure each year. For its fruit exports, the strategy is no different (Kapuya, Chinembiri & Kalaba, 2014). The nation produces 4.7 million tons of fruit annually, which is significantly more than the population consumes (Haasbroek, 2013). Citrus makes up 55% of this figure, whilst pome and stone fruit account for 34%, table grapes 6%, and the remaining 5% being sub-tropical fruit and nuts (Liphadzi, 2015). With citrus making up such a large segment of the market, it is clearly an important industry for the country. Figure 3 shows the segmentation of the SA fruit market.

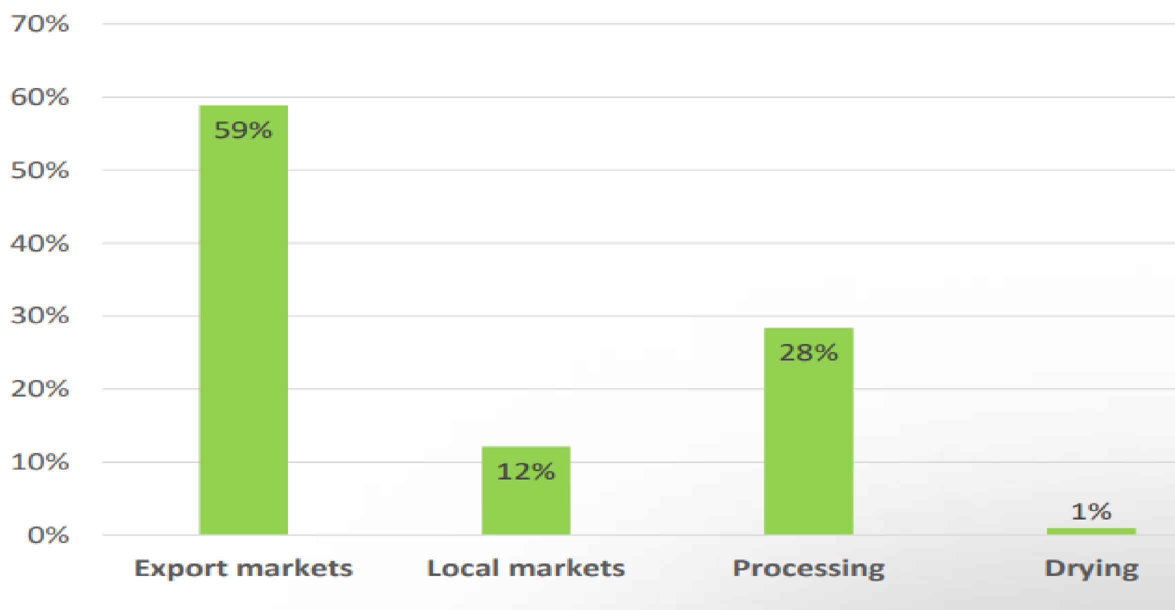

Figure 3: Segmentation of South African fruit market

Source: Liphadzi (2015)

Around half of the country's agricultural exports are in the form of fresh fruit. This amounted to approximately $3.7 billion in 2018 (WTEx, 2019). Agriculture makes up 2.59% of SA's GDP, which is approximately R74.1 billion (South African Market Insights, 2019). Since fruit exports account for 50% of agricultural exports, it is a major role player in the country's economy (Liphadzi, 2015). Supply and demand are what drives South African fruit exports, which are a significant creator of foreign currency. Ninety percent of the money that is generated by fruit farming comes from outside the country (Steenkamp, 2016). The industry is an important job creator and provides around 400 000 people with employment throughout its value chain (Steenkamp, 2016).

SA's fruit industry was regulated prior to 1996, but deregulated in 1997 when the Citrus Board and Deciduous Fruit Board decided to disband (Ortmann, 2005). This new, deregulated fruit industry sprouted many opportunities for entrepreneurs and lead to the establishment of a significant number of new, privately owned exporting entities (Ortmann, 2005). Exporting is a profitable industry in SA since the Rand has a general tendency to decline compared to currencies like the Dollar and Euro (major currencies) (Ortmann, 2005).

SA has notably suitable conditions for fruit farming; hence, farmers are able to cultivate a large variety of fruit in the country. It is suitable for the production of all three main fruit categories, namely deciduous fruit, citrus fruit and subtropical fruit (Ortmann, 2005). Figure 4 is a map that illustrates where the different fruit farming regions is SA are located – the main determinant of fruit selection is the conditions in the region.

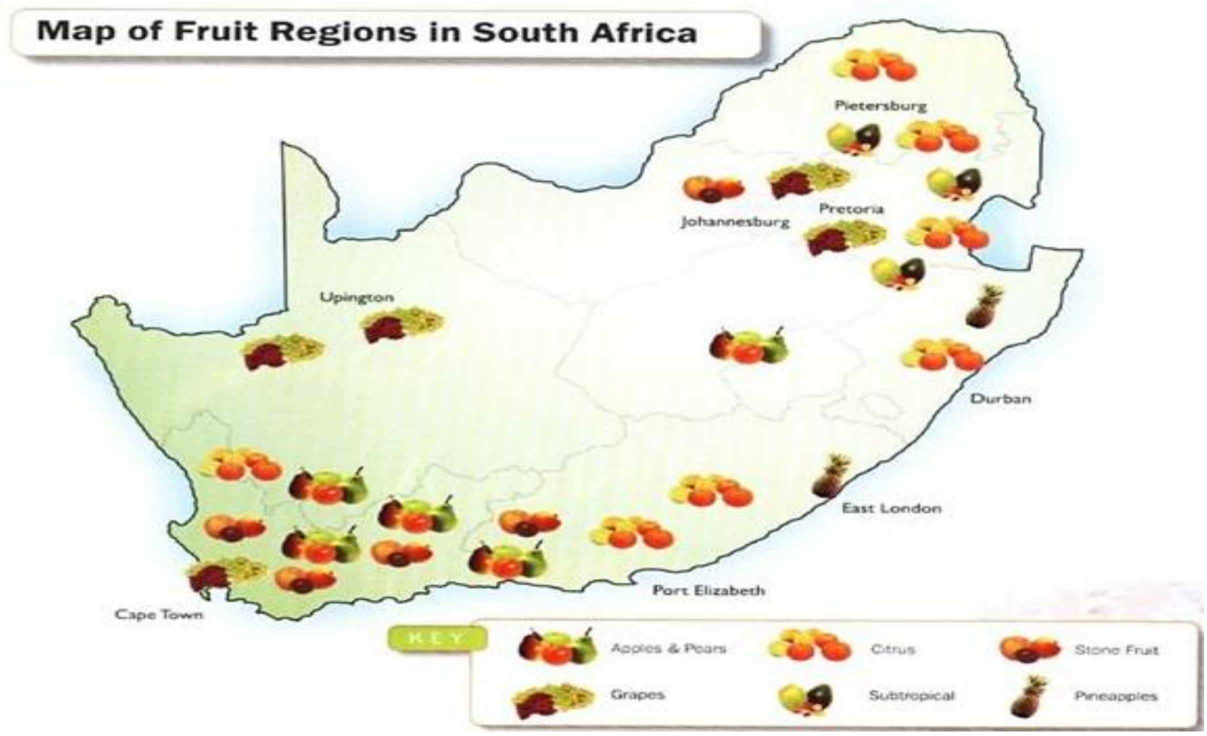

Figure 4: Fruit production regions in South Africa
Source: Liphadzi (2015)

SA's main deciduous fruit types are apples, apricots, grapes, nectarines, peaches, pears and plums. In terms of citrus, the country produces oranges, mandarins (soft citrus), grapefruit, lemons and limes. The subtropical fruits farmed in SA are mainly avocadoes, mangoes, litchis and bananas, but there are also a number of farmers producing ginger, macadamias, melons, papayas and pineapples (Ortmann, 2005). Because of such a large variety of fruit being cultivated, harvesting occurs throughout the year. Figure 5 illustrates the harvesting windows of the various fruit types in SA.

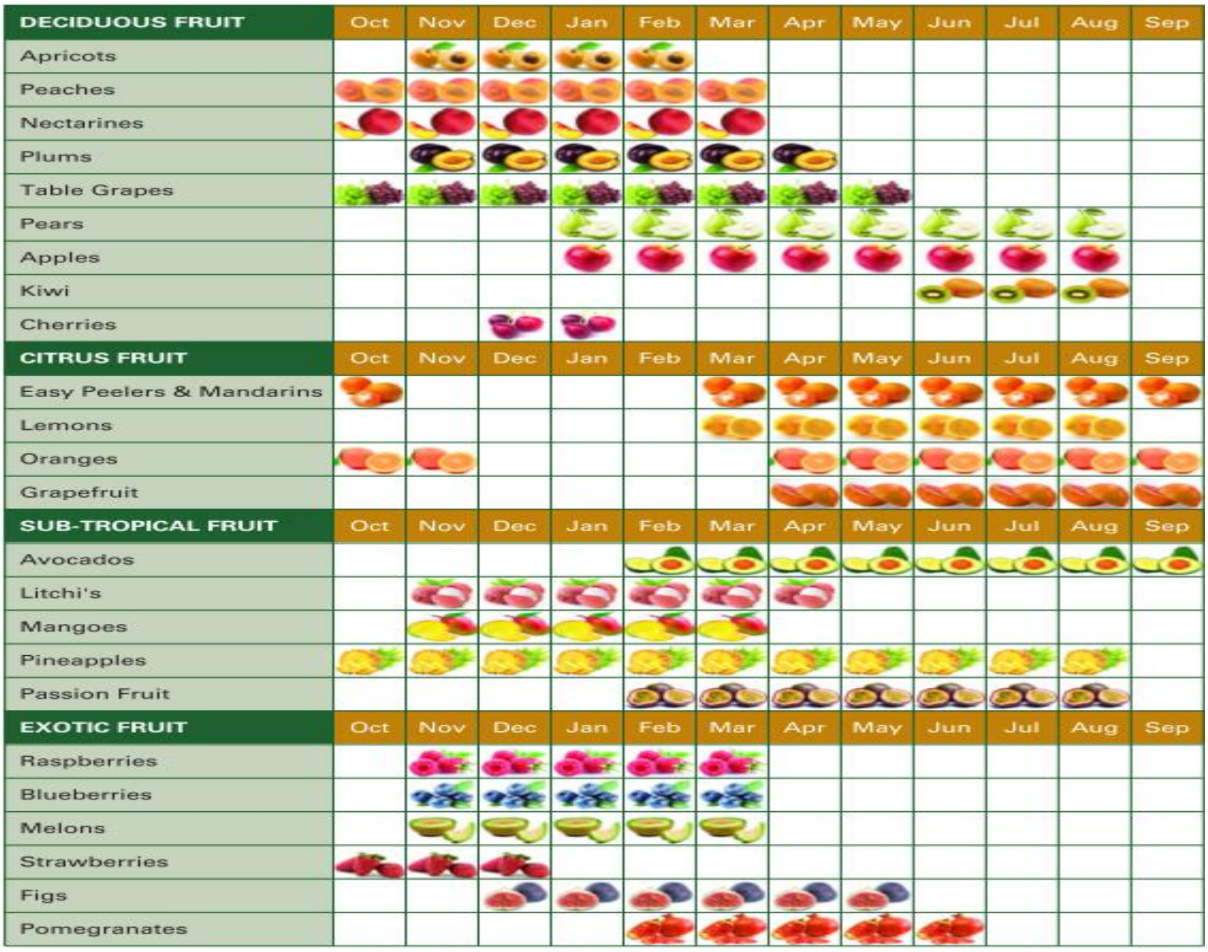

Figure 5: Abridged seasonal fresh produce calendar of SA

Source: *Fresh Food Trade SA 2017* (2017)

As shown on Figure 5, a short window of three months (December – February) is the only period when citrus harvesting stops in SA. However, Figure 5 only serves as a guideline and each season is unique. The deviating conditions in different parts of the country make the harvesting periods shorter/longer/earlier/later depending on the region in which they are produced (Ortmann, 2005). For example, table grapes (in this case of Thompson seedless) may be ready to harvest from the latter stages of November until the beginning of February in the Orange River area, while the Berg River area only starts harvesting from January to March. On the other hand, in the Hex River area, the harvesting period stretches from January to April (Ortmann, 2005).

2.4 SOUTH AFRICAN CITRUS INDUSTRY

2.4.1 OVERVIEW

As mentioned in the previous sub-section, Citrus production makes up 55% of SA's annual fruit production (Liphadzi, 2015), which means that it is one of SA's most important fruit groups in terms of gross production and value (Mogala, 2016). Limpopo, the Eastern Cape, the Western Cape and Mpumalanga are SA's main citrus farming provinces (Citrus Growers Association, 2018). Figure 6 is a map that illustrates these regions. Citrusdal, which is where this specific study originates, is in the Western Cape, approximately 180 km from the Port of Cape Town.

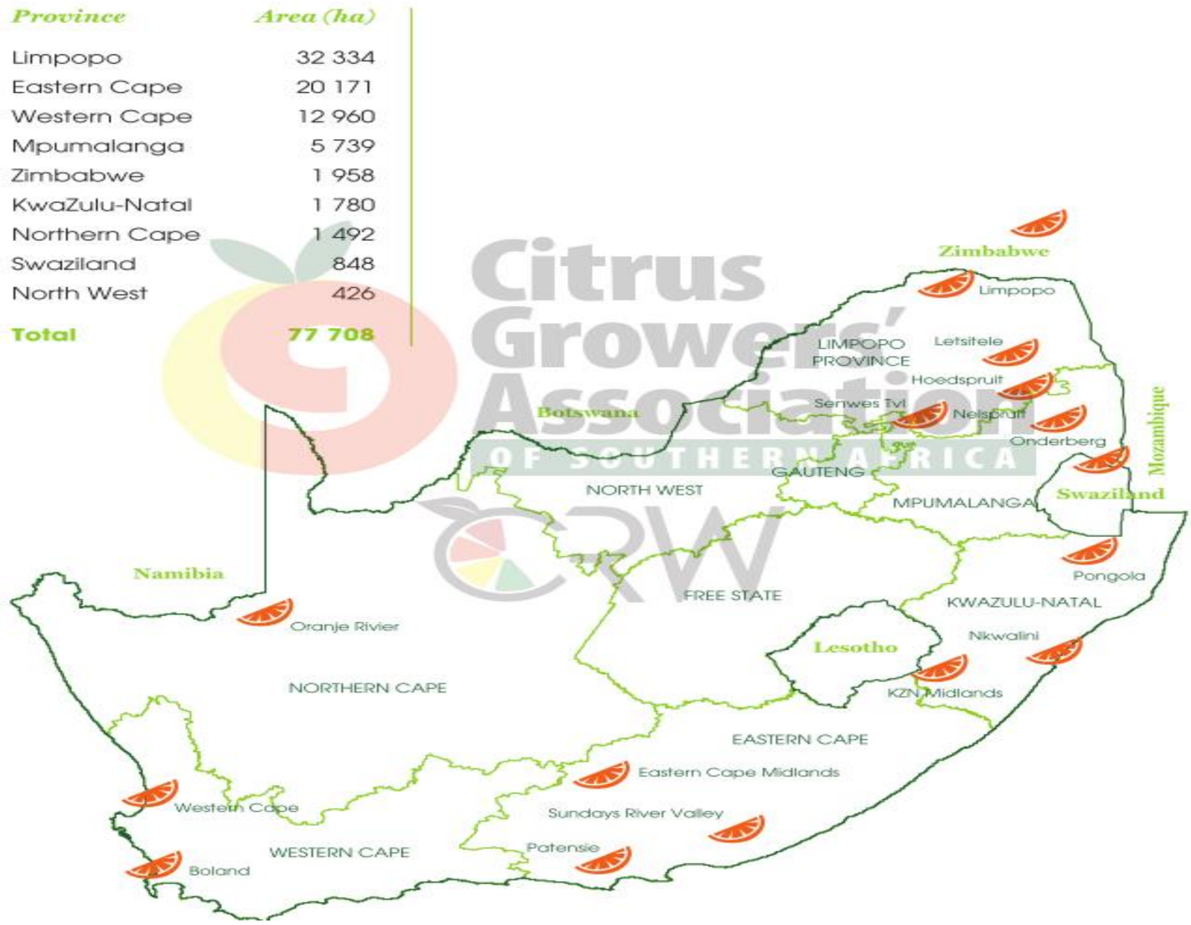

Figure 6: Citrus producing regions in SA

Source: Citrus Growers Association (2018)

The variations that were chosen are two of the most popular in the Western Cape, with Soft Citrus accounting for 46% and Navels for 27% of the province's production (About Citrus in SA, 2017). Clementines form part of the soft citrus variety. This figure is not the same as the rest of the country, as the most planted cultivars are Valencias (37%), followed by Navels (21%), Soft Citrus (17%), Lemons & Limes (15%) and Grapefruit (10%).

2.4.2 EXPANSION

In terms of hectares planted, Lemons and Limes have seen the biggest growth in SA with approximately 1300 additional hectares planted in 2017. Soft Citrus have also experienced a large growth figure of approximately 1200 hectares. Valencias, Navels and Grapefruit have smaller planted figures at approximately 350, 250 and 100 hectares planted (Citrus Growers Association, 2018).

The Eastern Cape planted the most hectares in 2017, at approximately 570 hectares and the Western Cape has the second largest planted figure at approximately 320 hectares, followed closely by Limpopo (310 hectares). The Northern Cape and Mpumalanga have a significantly smaller amount of new hectares planted (Citrus Growers Association, 2018). Such a vigorous crops planted figure in the Western Cape and the country shows what an important horticultural industry citrus farming is for the province (and country) and highlights the importance of this study. Figure 7 illustrates the number of new hectares planted by each province.

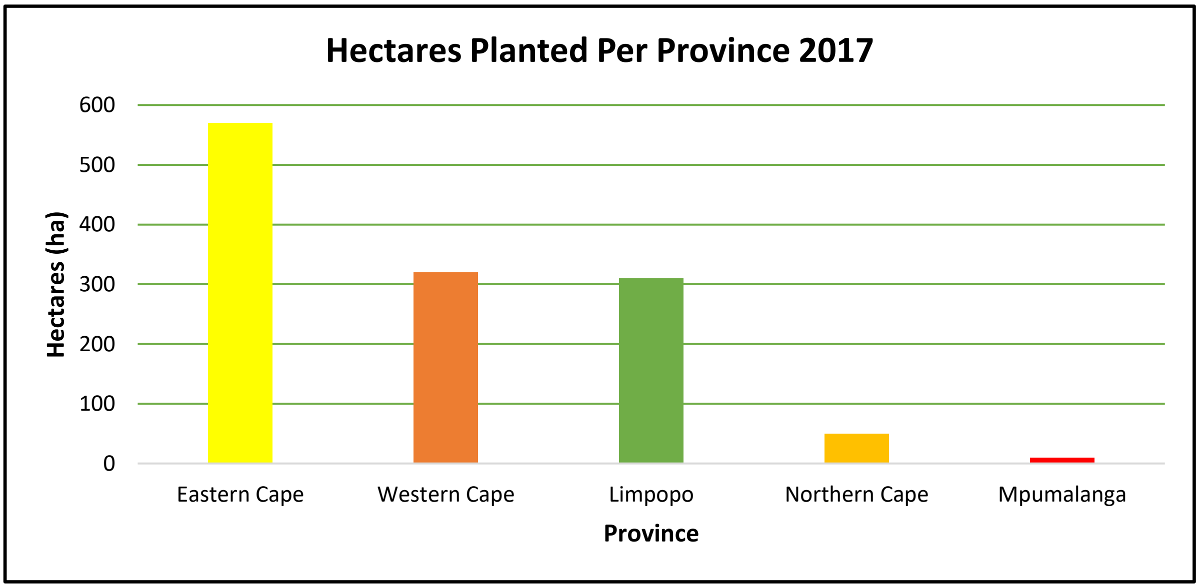

Figure 7: Hectares planted per province in 2017

Source: Adapted from Citrus Growers Association (2018)

Over the past five years, budwood sales [a budwood is a small premature twig from a new cultivar that farmers merge with a mature rootstock (the basis of a previous cultivar that was already planted and rooted), instead of planting a new tree] in SA have increased at a consistent level, amounting to 6 778 633 in 2017. Farmers combine young budwoods with mature rootstocks from different cultivars instead of planting new trees. The Western Cape was the second largest buyer of budwoods at 2 145 430, preceded only by Limpopo whose budwood sales totalled 2 202 851. The Eastern Cape was in third place at 1 363 402 (Citrus

Growers Association, 2018). Once again, the significant buying power and growth of the industry in the Western Cape supports the value of this study.

2.4.3 EXPORTS

Due to the ongoing drought that SA is experiencing at present, the country's citrus exporting figures have been almost stagnant over the past five years and declined in 2016. That year, the country experienced an extreme drought. In 2017, exports showed a substantial growth figure compared to 2016 and was also higher than 2015's figure, which is a positive sign (Citrus Growers Association, 2018). Figure 8 is a depiction of SA's yearly total citrus exports since 2008.

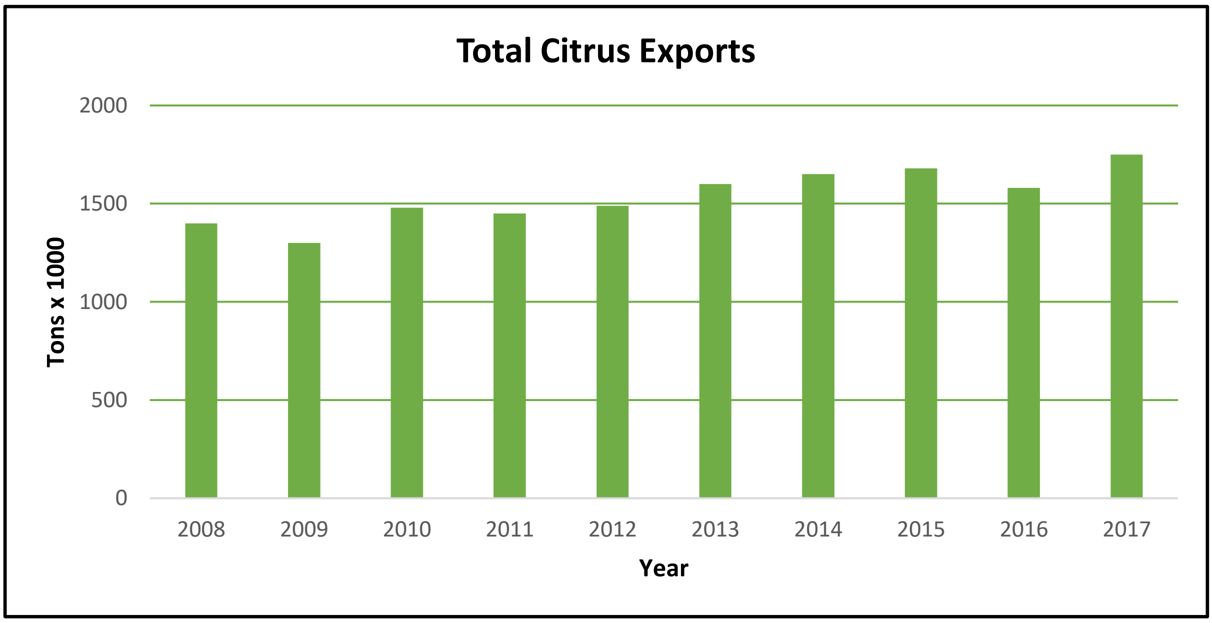

Figure 8: SA's historical exports
Source: Adapted from Citrus Growers Association (2018)

SA's main citrus exports are oranges. They represent 14% of the market and are ranked second in world exports (Mogala, 2016). Forty-three percent (43%) of the country's total citrus exports are Valencias, while 17% are Navels. Over the past five years, orange exports have shown zero to negative growth, which was mostly because of the drought. In 2016 especially, there was a substantial dip in orange exports, and the negative deficit compared to 2015 is yet to recover. Of the 1 362 651 tons of oranges that SA produced in 2017, 1 085 491 were exported, meaning that the orange market is highly export driven. Limpopo is the largest producer of Valencias, and the Eastern Cape is the province that produces the most navels.

Lemons & Limes are SA's third most exported citrus at 16%. The last five years have shown a positive curve for the country's Lemon/Lime exports, with 2017 being significantly higher than the previous four years. Lemon & Lime exports reached a record 290 000 tons in that year. The Eastern Cape is at the forefront of lemon and lime production in SA.

Thirteen percent of the country's citrus exports are in the form of grapefruit. It is therefore, fourth on the list of citrus exports from SA. In 2013, the country had a record high export figure for this variety at approximately 250 000 tons exported. The Grapefruit exporting values have not reached these levels again and have stagnated over the past four years. 2017 is the closest Grapefruit exports came to the 2013 volumes – approximately 230 000 tons (Citrus Growers Association, 2018). Limpopo is the country's main Grapefruit producing province.

Soft Citrus finds itself fifth on the list of citrus exports from SA at 11%. As mentioned earlier, the Western Cape is the largest role player in the South African Soft Citrus industry. It produces 40% of the country's soft citrus, with its nearest rival being the Eastern Cape at 30% (Citrus Growers Association, 2018). This variety is included in the study (in the form of Clementines) as it plays and important role in the Western Cape's horticultural economy. In the case of soft citrus, 201 554 tons of the total 261 046 that were produced were destined for exports, meaning that the Soft Citrus industry is also export driven.

Soft Citrus has shown a growth curve over the last five years and has experienced significant growth in the Western Cape as well. As mentioned, in 2017, approximately 200 000 tons of Soft Citrus were exported from SA, which is significantly more than in 2016. What is surprising about the past five years' Soft Citrus exports, is that the season that experienced the most exporting growth was 2015/2016. The country experienced a severe drought in that year, but Soft Citrus exports still increased – by approximately 30 000 tons (Citrus Growers Association, 2018). There is currently a global demand for new, different Soft Citrus cultivars, as a result of the increased demand from the industry (Stone, 2017).

2.4.4 LABOUR AND ECONOMIC GROWTH

SA's National Growth Path (NGP) states that the country should increase its exports by focussing on countries with a high consumption of South African products as well as countries with rapidly growing economies. The citrus industry has been identified as one of the industries with the highest growth potential for exports and should be used to strengthen the country's economic growth percentage (Kapuya *et al.*, 2014).

The citrus industry is a highly labour-intensive industry in SA, making it a significant job generator. It employs approximately 90 000 people nationwide and is the single largest agricultural employer (Kapuya *et al.*, 2014), which the orchards and pack houses are largely responsible for (Mogala, 2016). Furthermore, citrus production leads to a number of indirect jobs throughout the SC, such as transport and port handling (Mogala, 2016). Its labour-intensity is one of the major factors for its recognition as a key growth sector for SA's exports. The benefits are two-fold, as it can grow the economy while simultaneously reducing unemployment (Kapuya *et al.*, 2014). The Western Cape has the most farmworkers of all the

Provinces in the country – approximately 121 000 people – and the citrus industry makes a large contribution to this figure (Andrews, 2012).

The industry is governed by a set of strictly implemented labour laws regarding the rights of employees and payment standards (Bhorat, Kanbur & Stanwix, 2014). These laws include the Labour Relations Act, the Basic Conditions of Employment Act, Employment Equity Act, Skills Development Levies Act and the Unemployment Insurance Act (Labour Law In SA, 2018). These labour laws can make life difficult for producers and exporters, and may lead to government intervention and employee strikes, if undermined (Bhorat *et al.*, 2014).

Europe is SA's largest exporting destination for citrus at 33%, it is followed by the Middle East (18%), South East Asia (16%), the United Kingdom (9%), Russia (9%), Asia (8%) and North America (6%) (Citrus Growers Association, 2018).

In 1996, the South African government implemented the Marketing of Agricultural Products Act, which led to the deregulation of the fruit industry in October 1997 (Kruger, 2000). This meant that producers and exporters could now independently make decisions regarding the marketing of fruit and fruit products in SA, dismantling the monopoly that once controlled the industry. Therefore, the South African fruit industry (including the citrus industry), is very competitive. It has also presented the industry with many opportunities – including logistical opportunities (Kruger, 2000).

The fact the producers are frequently creating new mutations and cultivars enhances global competition. Global markets are continuously looking for something different and like to experiment with different types of citrus, motivating the industry to innovate and produce something unique. Customers want citrus fruits that are sweeter, seedless and easier to peel (Stone, 2017).

Many of the cultivars that exist today came into existence unintentionally from cross-pollination between orchards. Sometimes, these new mutations are exactly what consumers were looking for (Stone, 2017). SA's successful adoption of new varieties and production strategies that focus on quality are regarded as the most significant contributors to the country's recent citrus export performance (Kapuya *et al.*, 2014).

2.5 CITRUS AND TEMPERATURE

The following section highlights the importance of temperature control for the shelf life and quality of citrus by summarizing several previous studies on the subject.

2.5.1 FORCED COOLING OF CITRUS

Abnormal temperatures are harmful to citrus and excessive heat/cold due to weather conditions can have debilitating effects on the quality of the fruit (Liu *et al.*, 2014). Temperature is regarded as the most important factor concerning quality in the post-harvest stage of most fresh produce [Lafuente, Zacarías, Sala, Sánchez-Ballesta, Gosalbes, Marcos, González-Candelas, Lluch & Granell (2005); Thompson (2008)]. The main reasons for force cooling fruit are to retard moisture loss and minimize decay-causing organisms. It helps prevent biochemical reactions and slow down fruits' respiratory rate. In addition, it limits ethylene production and retards ripening. By implementing properly maintained cold chain practices, the shelf life of fresh produce extends significantly.

Different techniques exist for the force cooling of fruit (including citrus), some more commonly used than others are and usually situation specific. Room cooling, forced-air cooling, hydro-cooling, evaporative cooling and vacuum cooling are all examples of these techniques (Ngcobo, 2008). In the case of the South African citrus industry, two types of cooling are the most popular and usually occur in tandem. The first is a form of hydro cooling – previously mentioned drenching. This technique removes field heat from the citrus shortly after harvesting. The fruit is drenched in a water-based fluid that contains various chemicals that kill pests and protect the fruit from fungi that lead to decay.

The second cooling technique is forced-air cooling. After the citrus have been harvested, degreened and packed, road freight carriers transport the pallets to a cold storage facility where they are cooled down to -0.6 ºC for 72 hours prior to loading on a conventional vessel. This is done in accordance to the Steri pre-conditioning protocol, towards which there is a lot of criticism, as it is believed to cause chilling injuries (Defraeye, Verboven, Opara, Nicolai & Cronjé, 2015). Other disadvantages of the protocol are the extra costs incurred and the increased handling that the fruit undergoes. In modern times, there has been a noticeable shift from conventional shipping to reefer container shipping, which is more convenient and can transport the same volumes (Defraeye *et al.*, 2015).

Recently, the South African citrus industry started introducing a new loading technique, called 'ambient loading.' This loading technique serves as an alternative to forced-air cooling and has the potential to reduce costs and simplify logistical practices. The technique entails that the citrus are loaded into a reefer container at the pack house and are force-cooled inside the container during the sea leg. The theoretical benchmark for a container to achieve the required temperature is around five days, however, in practice this is not the case. It usually takes around seven to eight (Defraeye *et al.*, 2015).

Currently, in SA, ambient loading is only possible with less-sensitive citrus fruit (Valencia oranges, lemons and grapefruit). Furthermore, if a consignment's pulp temperature is above 22 ºC, the pallets must be force cooled. In other words, it is not possible to transport some soft citrus varieties by means of reefer containers (Defraeye *et al.*, 2015). Exporters from Citrusdal prefer reefer vessels to container shipments, as it is the cheaper option and they have been doing it this way for a lengthy period of time.

2.5.2 TEMPERATURE SPIKES

Temperature spikes, like temperature breaks, have a negative impact on fruit quality (Khumalo, 2018). These temperature spikes are especially prominent when the fruit has not entered the cold chain yet. A rise in temperature does not have to progress all the way to a temperature break for the change to have a negative impact on fruit quality. Temperature spikes lead to fruit sweat, moisture loss and, ultimately, advanced decay (Khumalo, 2018).

A temperature spike occurs any time the temperature rises along the export cold chain. As mentioned earlier, the concern that SA is losing substantial amounts of fruit produced each year due to breaks in the cold chain is a major concern for the industry (Freiboth *et al.*, 2013). Joshi, Banwet & Shankar (2009) found that in developing countries especially, maintaining the integrity of the cold chain is a major problem for exporters and farmers, and that it is the single largest contributor to the significant produce losses that these countries are experiencing.

They also state that cold chain maintenance is not a result of individual efforts, but of horizontally (role players in the same departments, levels and businesses) and vertically (role players in different departments, levels and businesses) integrated cold chain management. This instigates higher transparency and better control over the cold chain. Proper cold chain practices are normally rejected, because exporting entities (including farmers and port authorities) want to speed up the exporting process, because of limited time and a large through-flow of fruit (Haasbroek, 2013).

2.6 SPECIAL PROTOCOL FOR CITRUS EXPORTED TO THE USA

Citrus exported from SA that are destined for the USA must undergo a special Steri preconditioning program. The program is applicable to all citrus cultivars and has various functions. The following sub-sections discuss these functions.

2.6.1 STERI PROTOCOL

As mentioned previously, exported citrus from SA to the USA, China, Korea and Thailand undergo a mandatory period of exposure to -0.6ºC for at least 24 days. This is known in SA as the Steri protocol (Hordijk, 2013). The protocol's function is to ensure the elimination of any remaining insect larvae contained within the fruit. Steri, however, is often a controversial subject, as it is believed to cause chilling injury (CI), something that section 2.8.3.1 discusses in further detail (Hordijk, 2013).

The protocol originates at the cold storage facilities in Cape Town, where Company K pre-cools the fruit for a minimum of 72 hours at -0.6ºC. The protocol targets various insect-types, but the main culprits are the false coddling moth (FCM) and the Mediterranean fruit fly (Hordijk, 2013). It is important that the temperature of -0.6ºC is maintained from SA until the USA to reduce respiration rates and moisture depletion (Hordijk, 2013). Only United States Department of Agriculture (USDA) - Animal and Plant Health Inspection Service (APHIS) approved vessels may carry the produce. These vessels must possess a valid, APHIS-issued, certificate of approval (National Department of Agriculture, 2008).

Before a vessel is loaded, official PPECB personnel, authorized by the USDA-APHIS, must calibrate the temperature monitoring devices and recording equipment. The same condition applies before a ship may be dispatched (National Department of Agriculture, 2008). No unloading will occur from a cold room unless it has been approved by the PPECB, who ensure that the room is at the correct temperature and meets sanitary requirements (National Department of Agriculture, 2008). Furthermore, all vessels are required to register at the USDA-APHIS and must have the required number of monitoring sensors that monitor pulp and ambient temperature. Prior to off-loading in the USA, the temperature log must be inspected and approved by the USDA-APHIS (National Department of Agriculture, 2008).

2.6.2 CONDITIONS OF ENTRY

A phytosanitary certificate, issued by the South African Department of Agriculture, must accompany each shipment that arrives in the USA. The following declaration is compulsory on each certificate: *"The citrus fruit in this consignment was grown in and packed in SA in the Western Cape Province and in the Northern Cape Province in the districts of Hartswater and Warrenton."* The above-mentioned areas are black spot free, as declared by the USDA-APHIS after thorough inspection. Therefore, citrus that were cultivated in these areas are allowed to enter the country (National Department of Agriculture, 2008).

Furthermore, each box must be properly marked and contain accurate information regarding the exporter, country of origin, pack house details and Production Unit Code (PUC), fruit count and calibre, net weight of the box and correct description of the variety and cultivar. No pallet may enter the country if it does not possess an official label stating: *"USDA Passed."* The USDA-APHIS are responsible for issuing these labels (National Department of Agriculture, 2008).

2.7 CITRUS QUALITY

All fruit types are living objects, which means they will gradually decay in accordance to their average lifespan post-harvest. Because citrus fruits are usually stored before they reach their fresh consumption markets, they are vulnerable to fungal diseases as well as physiological defects (Duan, OuYang & Tao, 2018). This leads to the development of numerous techniques that counter-act the effect of ageing, and extends the shelf life of fresh produce (Goedhals-Gerber, Haasbroek, Freiboth & Van Dyk, 2015). One of the techniques that has a significant influence on this process is cold chain management (Haasbroek, 2013).

Temperature influences quality throughout the cold chain, with various factors playing a role, the first being field heat. The sun combined with the respiration of the citrus increase the fruits' temperature. Therefore, workers move them from the orchard to pre-cooling as quickly as possible to minimize the influence that this field heat has on the shelf life. Respiration's influence on fruit quality cannot be underestimated, as strawberries for example, respire eight times quicker at 28ºC than at a controlled temperature of 0ºC (Jobling, 2002). From pre-cooling, it is important that the various role players involved maintain the cold chain consistently to minimise post-harvest losses. Microorganisms grow comfortably in higher temperatures, but the cold chain hampers their development (Jobling, 2002).

2.7.1 QUALITY FACTORS

Various factors have an influence on citrus quality, ranging from climatic conditions to farming practices. The following sub-sections expand on these factors.

2.7.1.1 Climate

Climate is the largest influencer of citrus quality (Zekri, 2011). With that said, the different citrus cultivars' responses to varying climatic conditions are diverse. The biggest difference can be detected in market quality (Zekri, 2011). Navel oranges, for example, develop the best in Mediterranean climates, where winters are cold and wet, and the summers are warm and dry. When navel oranges are grown in tropical conditions, they tend to be overly large and have poor colouring (Zekri, 2011). On the other hand, most grapefruit cultivars reach optimum quality in hotter climates and winters that are not as cold. Valencia oranges have managed to adapt to most of the favourable citrus growing regions' climates (Zekri, 2011).

In sub-tropical climates, there is a prolonged window during the winter months when the temperature will drop below 21ºC. This drop enhances quality as it allows the trees to be dormant for a couple of months. The dormant state promotes bud growth and produces flowers. In tropical climates, citrus trees are rarely offered a dormant window by the warmer conditions (Zekri, 2011). Therefore, citrus that are grown in sub-tropical climates tend to have an advantage in terms of quality (Zekri, 2011). In tropical conditions, where temperatures and average temperatures are high throughout the year, oranges and tangerines remain green, as the chlorophyll in the peel does not degrade. In sub-tropical climates with cold winters, both oranges and tangerines will develop a bright orange peel (Zekri, 2011).

Citrus maturity accelerates in lowland tropical areas and do, therefore, not have enough time to build up Total Soluble Solids (TSS) while the sugar/acid ratio in the fruit increases substantially, because of a rapid decline in acidity. These variations cause the citrus to dry out quickly and lose taste. Citrus fruit with optimum TSS have the lengthiest accumulation in cooler coastal regions, while the highest acid levels are found in areas that are arid/semi-arid (Zekri, 2011).

2.7.1.2 Growth regulators

Farmers can attain economic advantages by utilising plant growth regulators (PGR's). These regulators can be significantly advantageous if their timing is accurate. If PGRs are applied at the right time on the right cultivar, they can improve fruit set, enhance fruit size by reducing the crop load, prolong the harvest season by delaying rind ageing, and reduce pre-harvest fruit drop (Zekri, 2011).

Farmers use two main PGRs. The first of these is Gibberellic acid (GA). Experts prescribe GA for cultivars with weak parthenocarpy as well as poor cross-pollinating characteristics. It may help these cultivars to improve fruit set and produce better crops. It also assists with juice extraction and controls flowering to further aid with fruit set (Zekri, 2011). The second type of PGR is Naphthalene acetic acid (NAA). In situations of excessive set (a situation where trees over-produce and cannot provide enough nutrients to deliver high quality citrus fruits), farmers utilise NAA to thin the fruit. Excessive fruit set involves trees that produce too vigorously, causing undersize fruits. This thinning process improves fruit size (Zekri, 2011).

2.7.1.3 Cultivar selection

This quality-influencer is the most controllable by the farmer. Depending on what a farmer is trying to achieve with their produce, cultivar selection plays an important role. For example, some cultivars have excellent colour, size and juice sugar, but other cultivars produce higher yields (Zekri, 2011).

Apart from the cultivar and its characteristics, horticultural characteristics also play an important role. For example, some rootstocks behave differently with varying budwoods. When a Valencia orange budwood is budded on Cleopatra mandarin rootstock, the fruit size will consistently be too small for export markets. Some rootstock and budwood combinations may produce superior quality to other combinations, making the latter obsolete (Zekri, 2011).

2.7.1.4 Irrigation and nutrition

As previously mentioned, climate and genetic make-up have the largest influence on citrus' development, but production practices can be an effective way for farmers to differentiate themselves in the marketplace. Proper irrigation, for instance, will lead to better fruit size, weight, juice content and sugar: acid ratio. Excessive irrigation, however, may have suffocating effects on trees, which negatively impacts fruit yield and quality (Zekri, 2011).

Citrus orchards should have a well-balanced irrigation and nutrition program to ensure consistent, high quality yields. Trees with proper irrigation and nutrition will be stronger and have a better tolerance for pests and diseases. If an improper program is in place, trees will likely produce a lower yield with oversize fruit and poor quality. The most notable nutrients that citrus trees require are nitrogen, phosphorus and potassium; however, there are also a significant number of other important nutrients. If these nutrients are absent or in excess, it will negatively influence yield and quality (Zekri, 2011).

Nitrogen (N) enhances juice and acid content and TSS, but excessive N will cause abnormal growth and insufficient TSS. Low levels of N will cause poor fruit set and low yields (Zekri, 2011). Phosphorus reduces the acid content, which creates a more desirable soluble solids: acid ratio. Potassium (K) ensures better production, size, fruit colour and peel thickness (Zekri, 2011).

2.7.1.5 Sunlight and pruning

Citrus trees are generally robust and may still produce acceptable yields when planted in the shade, but maximum production will occur when the trees are exposed to full sunlight and penetration through the canopy is efficient (Zekri, 2011). This is where pruning becomes a very important aspect of citrus farming. Pruning prevents crowding and optimises flowering. The number of fruit that are set have a profound effect on the quality of the citrus (Zekri, 2011).

The fruit set, insufficient peel texture, fruit shape and colouring are often poor with a high dispersion in quality - even for fruit from the same tree. Fruit grown on the inside of the canopy with less exposure to sunlight will have poor TSS compared to fruit on the outside of the canopy (Zekri, 2011).

If a tree produced an excessive yield one year, it will not flower sufficiently in the next year and will produce a poor yield – this has been well established by previous research (Zekri, 2011). The lower yield is a result of a depletion of carbohydrates, meaning that the available carbohydrates are not enough for the tree to produce a high yield again. Proper pruning can be an efficient tool for farmers to gain a competitive advantage over their competitors (Zekri, 2011).

2.7.2 QUALITY CRITERIA

Citrus fruits are tested and inspected at various points in the SC to ensure that they are in an acceptable condition. The two main entities responsible for these tests are the PPECB of SA and the USDA of the USA. Section 2.9 discusses these entities. The section below discusses the important quality factors during an inspection.

2.7.2.1 Juice Content

Insufficient juice content can cause granulation, which means that the fruit becomes dry and stalls on the inside (Sinha, 2017). Citrus juice content must be at a well-balanced level for customer satisfaction. Inspectors calculate the juice percentage by first weighing the fruit and then the juice, which they extract by using a ream juicer. They weigh the juice and divide it by the weight of the fruit to calculate the juice percentage. Generally, customers prefer higher juice contents (Citrus Australia, 2011).

2.7.2.2 Brix Content

The Brix value of citrus is the sugar content. The higher the Brix value, the higher the sugar levels are in relation to juice content (Citrus Australia, 2011). Consumers generally prefer citrus with higher Brix values, because they tend to be sweeter. The Brix value, however, is not the only determinant of sweetness, since the acid content also influences the sweetness. The effects of a high Brix content may be countered by the effects of a high acid content (Eddy, 2013).

2.7.2.3 Acid Content

Citrus contains the highest amount of Citric acid of all fruit types. It is especially prevalent in lemons and limes – hence the sourness (Canon, n.d.). It is the main organic acid that citrus produce and is contained in the juice sacs. It plays a major role in fruit quality and taste (Hussain, Shi, Guo, Kamran, Sadka & Liu, 2017). When the acid content is too high, the fruit will likely be too sour. If it is too low, the fruit will be too sweet, and experience accelerated decay. This is because citric acid is a strong preservative. These preserving qualities have been utilised in various food types for a long time (Hussain *et al.*, 2017). When testing for the acid content, inspectors utilise a pipette to extract the juice. Sodium hydroxide (NaOH) is then mixed with the juice and the acid content is measured with a burette (Citrus Australia, 2011).

2.7.2.4 Brix to acid ratio

The sugar to acid ratio determines whether citrus has adequate flavour for consumption. The ratio is calculated by dividing the Brix value by the acid percentage (Citrus Australia, 2011). The benchmark Brix to acid ratio for citrus quality is 8:1. However, researchers recently determined that BrimA, which involves multiplying the acid content with the factor k (usually a number between three and five) and then subtracting that number from the Brix content (i.e. Brim A = Brix – k x Acid) is a better benchmark for flavour (Eddy, 2013).

2.8 PESTS, DISEASES AND DEFECTS

2.8.1 PESTS

2.8.1.1 False Codling Moth

False Codling Moth (FCM) is a South African indigenous insect inhabiting citrus orchards. It can survive in a wide range of habitats and has been detected in all the citrus producing regions of SA, making it a substantial phytosanitary threat (De Jager, 2013). The pest has a negative impact on SA's citrus exports to several countries. It is one of the main reasons for the implementation of the STERI protocol, as the sub-zero temperature kills its larvae. The Citrusdal area, where this study found its origin, is especially susceptible to FCM (Stotter, 2009).

Most citrus variations are targeted, especially Navel oranges. Lemons seem to be a less favourable host. A study on FCM, conducted in Citrusdal (because it is such a problem in that area) found that the only other surrounding, naturally infested fruits in the area were acorns and guava fruit. Furthermore, it was discovered that male FCM were mostly confined to – or close to – citrus orchards or large orchards of substitute hosts (Stotter, 2009). If they were caught anywhere outside an orchard, it was in small numbers and not further away than 1.5 km.

The results were relieving to citrus farmers in the area, because it meant that the indigenous fynbos vegetation is not an adequate replacement host for the pest. Subsequently, only citrus orchards and substantial orchards of alternative hosts have to be treated with anti-pest programs (Stotter, 2009). The study also found that mass-migration between citrus orchards and substitute orchards is an infrequent occurrence.

However, the fact that FCM can survive on different hosts is sub-ideal. Added to this, the large variety of citrus cultivars means the season stretches over a lengthy period of time (approximately nine months). Both of these factors enable the pest to survive comfortably throughout the year, because the season is long and alternative hosts are available during the off-season (Stotter, 2009).

Even though citrus fruit is the only substantial host for FCM in the Citrusdal area, it can inhabit a wide range of other hosts in the Western Cape Province. This is a major concern for the farmers, because it complicates the control of FCM. They inhabit the custard apple, prickly pear, persimmon, bean, common oak, pomegranate, cotton, guava, olive, maize, sorghum, apricot, nectarine, peach, pear, plum, mandarin, orange, tangelo, tangerine, litchi, peppers, tea and grapes (De Jager, 2013).

FCMs also inhabit a wide range of wild crops like the Marula, wild plum, wild custard apple, *alubuca* sp., *Asparagus crassicladus,* red bush willow, Jade plant, African ebony, jakkalsbessie, castor oil plant, kudu berry, African walnut, Karoo boer-bean, Port Jackson willow, wild fig, waterbessie, red sour plum, wild olive, passion flower, real yellowwood, buffalo thorn, Kei apple, red milkweed and snake apple (De Jager, 2013).

FCM's eggs have a hemispherical shape and are translucent, making them hard to see for people who are inexperienced with their identification. Females usually lay their eggs singly in the rind of the fruit, except if they find a pierced area in the rind. They also lay them in the navel end of navel oranges. It is possible for a single fruit to contain more than 100 eggs; however, the average number per citrus is approximately 3 – 8 eggs (De Jager, 2013). Some acorns have been detected to have up to 25 eggs per acorn (Stotter, 2009). A single female can lay up to 800 eggs in its life cycle of approximately 30 – 174 days, which depends on the conditions (De Jager, 2013). This means that one female can destroy up to 100 fruits in its lifetime.

The larvae tend to suffer from a high mortality rate, mostly because of weather conditions. They are especially susceptible to low humidity and cold weather. It is rare for more than one mature larva to subsist in a single citrus fruit. However, it is possible for up to three mature larva to exist in one acorn (Stotter, 2009).

From December to April, FCM infestations can cause devastating fruit drops. In the most extreme cases, fruit destruction has been reported to be as high as 80%, giving the FCM well-earned, serious pest status (Hofmeyr & Pringle, 1998). Penetrated fruit will take between three to five weeks before dropping, while newly penetrated fruit are difficult to detect since fruit may show little signs of penetration. If a fruit is penetrated shortly before harvest, it is seriously threatening in terms of post-harvest decay (Hofmeyr & Pringle, 1998). The effectiveness of conventional insecticides is limited, as FCM-populations are infamous for having high tolerance for conventional control methods. FCM is therefore, usually controlled by using a multi-disciplinary approach, the most popular method being a mating disruption technique, better known as the Sterile Insect Technique (SIT).

Farms often utilise manual labour to combat FCM in a series of techniques known as 'cultural control.' As a preventative method, they usually remove native host species from areas surrounding orchards, confining the pest to the orchard itself. This enables the farmer to treat only the orchard with control methods. They drown any pupae in the soil by means of heavy irrigation. It is coupled with cultivation that will destroy any hibernating insects (De Jager, 2013). Furthermore, they destroy all infected citrus fruits. This includes hanging fruit as well as dropped fruit. The process should be repeated weekly (Hofmeyr & Pringle, 1998).

'Attract and kill' is a supplementary treatment to mating disruption (MD). The goal is to suppress FCM populations by luring males with pheromones (the hormone females use to attract males) and then killing them. This reduces mating, which leads to smaller FCM populations (De Jager, 2013). MD is another technique that is used to confuse and repel males, which also causes a depletion in mating numbers (Hofmeyr & Pringle, 1998).

SIT is a MD technique, which involves the release of sterile males in the area to mate with the females, causing them to lay infertile eggs. The overall goal of SIT is to destruct the insects' populations to such an extent that it is unable to recover (Bonizzoni, Katsoyannos, Marguerie, Guglielmino, Gasperi, Malacrida & Chapman, 2002). This technique proves to be the most effective. Stotter (2009) found a fruit drop reduction of 94.4% in navel orange orchards where the application of SIT occurred. A fundamental aspect of this technique is the over-flooding effect it creates. This makes the ratio of sterile males to wild males approximately 10:1 (Hofmeyr & Hofmeyr, 2004). Furthermore, SIT is environmentally friendly and host specific. It is easy to integrate with area-wide pest control programmes in current use (De Jager, 2013).

2.8.1.2 Mediterranean fruit fly

Ceratitis capitata, or the Mediterranean fruit fly (medfly) is widely regarded as one of the most successful agricultural and economic pests in the world, due to its high invasiveness and global dispersion (Karsten, 2011). The medfly has strong reproductive capabilities, grows rapidly (Lance & McInnis, 2005) and can tolerate a broad spectrum of climatic conditions (Nyamukondiwa & Terblanche, 2009). Global trade, human travel and adaptive biology make it highly invasive and a significant economic threat. As a result of the abovementioned, it was able to spread successfully from its assumed Afrotropical origin to numerous countries throughout the world (Karsten, 2011).

In Africa, females make use of approximately 150 different host plants to lay their eggs (De Meyer, Copeland, Wharton & McPheron, 2002). In this manner, it is unique from the FCM, which targets a significantly smaller number of host plants, as shown in section 2.8.1.1. It has the same approximate lifecycle as FCM at around 30-40 days and can produce up to eight generations per annum. Females can lay up to 500 eggs per year, which they oviposit under the skin of maturing fruit (Karsten, 2011).

The risk that fruit flies like the Medfly pose to the citrus industry is twofold – as is the case with the FCM. Firstly, because the larvae feed on the fruit and penetrate the skin as well as flesh, making it unmarketable. Secondly, any consignments showing evidence of fruit fly contamination upon arrival at a foreign destination will be banned from entering the country, leading to substantial economic losses (Barnes, 2000).

In SA, four different measures are currently in place for fruit fly control (Karsten, 2011). The first is a bait application technique (BAT), where food baits are set up on a localized spot in a tree. These food baits are combined with pesticides like Malathion, Dipterex and Rogor to kill the flies (Ekesi & Billah, 2006). Bait stations, which are the second technique, work similarly to BAT, except the bait and pesticides are now in a container trap. The flies can't escape the trap once they've entered (Ekesi & Billah, 2006). Thirdly, full-cover sprays over a whole orchard kill the flies within that orchard. This method, however, is under scrutiny for damage to the environment and its negative impacts on human and animal health. Society generally prefers methods that are more environmentally friendly (Karsten, 2011). One of these preferred methods is the previously mentioned SIT.

SIT, however, has a few shortcomings. These also apply to FCM and the Natal fruit fly, discussed in the next section. For some pests, SIT has proved to be highly effective, like the tsetse fly and screw worm, but there are other taxa that have proven more challenging to control with SIT (Lance & McInnis, 2005). For example, complicated lifecycles are difficult to predict, making it possible to miss some Medfly attacks. Insects also have the potential to cause significant damage even after being sterilised (Lance & McInnis, 2005).

Another problem with SIT is the difficulties experienced when attempting to rear high quality sterile males in laboratories. These males often find it hard to survive in normal conditions, let alone extreme conditions (Weldon, Prenter & Taylor, 2010). They may also struggle to mate with the females, as wild males' sperm have a fitness advantage over sterile males. Females then, prefer the wild males over the sterile males (Bonizzoni *et al.*, 2002).

The Medfly only travels approximately 21 kilometres in its lifetime and, therefore, rarely wanders far away from its release point. This means that for SIT to be effective, a thorough blanket of sterile males must be released, ensuring that the whole area is covered (Meats & Smallridge, 2007). If SIT facilitators leave gaps when they release the flies, it can have a profoundly negative impact on the effectiveness of a SIT program. Therefore, it is recommended that there should be some form of overlapping between release points (Karsten, 2011).

2.8.1.3 Natal fruit fly

The Natal fruit fly *(Ceratitis rosa)* shares various similarities with the Medfly, but there are several important distinctions. Like the Medfly, it is highly phytophagous and attacks a significant number of the same fruit species. It is, however, at present mostly limited to Eastern and Southern Africa (De Meyer, Robertson, Peterson & Mansell, 2007).

De Meyer *et al.* (2007) state that the Medfly is not unique in its invasiveness and that a number of other fruit fly species have managed to occupy terrains far from where they originated (Duyck, David & Quilici, 2004). The Natal fruit fly is one such species and is the second most significant fruit fly species in SA. It is a highly invasive member of the *Ceratitis* genus and occupies a large section of the African mainland (De Meyer, 2001). It has also invaded a number of the Indian Ocean's islands, including Mauritius and Réunion Island (White, De Meyer & Stonehouse, 2000). A concerning discovery with these island invasions is that the Natal fruit fly has managed to displace some of the Medfly populations that were previously introduced, meaning it could be more invasive (Duyck *et al.*, 2004). Studies have also found that the Natal fruit fly may have a higher tolerance for wet and cold weather, therefore, it could have better potential to inhabit areas with mild temperature conditions (Duyck *et al.*, 2004).

Most species in the fruit fly genus are considered economically important and quarintine worthy. Baliraine, Bonizzoni, Guglielmino, Osir, Lux, Mulaa, Gomulski, Zheng, Quilici, Gasperi & Malacrida, (2004) state that quarintine policies are one of the most effective ways to prevent the introduction of new species to a region, as control measures after an invasion have numerous limitations. It is therefore, important that quarintine workers are well-trained, in order to identify traces of fruit fly contamination as quickly as possible (Baliraine *et al.*, 2004).

2.8.2 DISEASES

2.8.2.1 Citrus Black Spot

Citrus Black Spot (CBS) is a fungal disease unique to citrus fruit. It is caused by a pathogen named *Guignardia citricarpa* Kiely and can infect the fruit itself, as well as the leaves and twigs of the trees. All citrus trees that are used for commercial production are susceptible to CBS, with the exception of sour oranges (and sour orange hybrids) and Tahiti limes (Carstens, Le Roux, Holtzhausen, Van Rooyen, Coetzee, Wentzel, Laubscher, Dawood, Venter, Schutte, Fourie & Hattingh, 2012). Lemons are especially susceptible. Initial discovery of CBS in an area is usually first detected in lemons and lemon orchards (Truter, 2010).

The two spores that CBS produce are firstly, waterborne conidia, which are asexual, and secondly, windborne ascospores, which are sexual. Ascospores seem to be the preferred mode of infection and are a product of perithecia, which develop on fallen leaves that have been infected (Carstens *et al.*, 2012). Perithecia can only occur on leaf litter – it is not present on fruit nor leaves that are still on a tree.

When surveying for the disease, spots on the fruit is a good indicator of infection, especially during the summer and at harvest time. In severe cases, abnormal fruit drop may also be an indication of CBS infection. The foliage may appear to be significantly unharmed in infected fruit. Farmers can manage the disease quite effectively by regularly applying protectants and systemic fungicides when required. If the aforementioned is coupled with sanitizing techniques (removal of twigs, leaves and fruit), fruit loss from CBS can be significantly reduced (Schubert & Jeyaprakash, 2010). Climatic conditions have also been found to restrict the disease - cold and wet conditions seem to be the most restrictive to CBS (Truter, 2010). This was a strong standpoint for SA's citrus exports to the EU as Paul, Van Jaarsveld, Korsten & Hattingh (2006) argued that conditions in the EU will make it impossible for CBS to germinate and spread.

Today, CBS occurs globally, including Southern African countries, China, Brazil and Australia. It has not yet been discovered in Mediterranean and European citrus producing countries, nor has it occurred in Chile, Japan, New Zealand or Central America (Potelwa, 2017). CBS introduced various phytosanitary barriers to trade, as countries understandably try to prevent the disease from threatening their black spot-free production areas (Truter, 2010). For many of SA's trading partners, CBS is seen as a disease that is quarantine-worthy (Carstens *et al.*, 2012).

CBS threatens farmers and exporters with various potential economic losses. If an orchard is heavily infected, the disease can cause premature fruit drop. The market value of infected fruit plummets and phytosanitary programs to control the disease are expensive to implement and manage (Truter, 2010). If an area is seriously infected, it may cause total loss of a consumable crop. It is possible for citrus fruit to only start showing symptoms while in transit or on arrival at an exporting facility. In such cases, it can lead to the rejection of an entire consignment. Therefore, commercial citrus production and exportation would be unfeasible without the control programs that are in place (Truter, 2010).

The legitimacy of a control program, such as the one between SA and the USA, must be determined by conducting a Pest Risk Assessment (PRA), supported by scientific evidence. These assessments consider the longevity, host specifications, and geographical distribution (as well potential geographical expansion) of such a disease. If a thoroughly conducted PRA suggests that the disease poses a low risk, control measures can be partly, or even completely removed (Truter, 2010).

SA has committed as a member of the World Trade Organisation Agreement on the application of Sanitary and Phytosanitary Measures, as well as the International Plant Protection Convention. This makes it responsible for implementing phytosanitary programs that protect growers and exporting entities from legal steps that the international community may take. It is also responsible for sharing reliable information on the existence and distribution of any pests and diseases with trading partners (Carstens *et al.*, 2012). In 2010, CBS in the form of *Guignardia citricarpa* was discovered in the state of Florida, USA, but the control measures between SA and the USA remain intact (Schubert & Jeyaprakash, 2010).

The USA only allows South African fruit produced in a black spot free area to cross their borders. Japan and India will allow any citrus that are free from visible CBS symptoms. As for the EU and Iran, citrus fruit that were produced in CBS-free areas or production sites where no infected fruit were found during inspection, will be considered for importing (Carstens *et al.*, 2012). Because the South African citrus industry is heavily reliant on exports, it is important to determine designated black spot free areas to protect its citrus industry.

In the EU, the maximum allowable amount of CBS interceptions from a citrus supplying country is five. For SA, this is a very hard standard to comply with and they regularly exceed that number. For example, in 2013, 36 cases of CBS were intercepted in citrus fruit that was exported from SA to the EU (Potelwa, 2017).

Only three provinces in SA are CBS-free. They are the Western Cape, Northern Cape and Free State provinces. All other provinces in the country are contaminated and strict measures are in place to ensure that the pathogen does not cross provincial borders and infect the rest of SA's citrus producing regions (Carstens *et al.*, 2012).

2.8.2.2 Green Mould

This is the most damaging disease to citrus in the post-harvest stage. It originates from a fungus called *Penicillium digitatum* and can have debilitating effects after harvest. Most of the damage occurs during storage and transportation activities (Duan *et al.*, 2018). *Penicillium digitatum* is a pathogen that attacks citrus by penetrating the fruit at wounded areas. The pathogen is abundant in orchards and pack houses and is very easily transported through the air, making green mould a serious threat to farmers and exporters (Duan *et al.*, 2018). Soft Citrus is the most susceptible to the pathogen, while Valencia oranges have shown the highest resistance in previous studies (Erasmus *et al.*, 2015).

'Drenching' is a preventative technique used to manage the disease. The citrus are drenched in a water-based fluid containing various chemicals; one of these chemicals, called *Imazalil* (IMZ) is specifically for preventing *Penicillium digitatum* from penetrating citrus. It is the most commonly used chemical throughout SA to prevent green mould. It is important to treat citrus with IMZ shortly after harvest as infections can occur as early as four hours after picking the fruit. The current protocol on South African farms is for citrus to be drenched within 24 hours of harvest. It is possible to prevent green mould within this timeframe (Erasmus *et al.*, 2015). There are several other ways of applying IMZ to citrus fruit. Dip tanks, sprays and wax applications are all popular techniques and a combination of the methods is also frequently utilised (Erasmus, Lennox, Jordaan, Smilanick, Lesar & Fourie, 2011).

Even though IMZ is highly effective at preventing green mould, the industry still experiences substantial losses at the hand of the disease and it remains a concerning problem for farmers and exporters. Erasmus *et al.* (2011) state that this is because IMZ residue loading levels in most pack houses are lower than the minimum proven effective levels. They also found that concentration, temperature of the substance, PH and exposure period all have an influence on IMZ residue loading. If residue loading is inadequate, control of the disease will be lost and pack houses may become IMZ-resistant – the *Penicillium digitatum* pathogen is capable of mutating in this manner (Erasmus *et al.*, 2011).

Long-term cold storage helps to contain and prevent green mould, because cooler conditions suppresses the *Penicillium digitatum* pathogen's growth. Combining IMZ application and cold chain practices are highly effective and may lead to a 20% increase in effectiveness compared to utilising only IMZ applications (Erasmus *et al.*, 2011).

2.8.3 DEFECTS

2.8.3.1 Chilling Injury

Chilling injury (CI) is an important sub-topic concerning this thesis, as it can be a direct symptom of poor cold chain management. As mentioned, a couple of times previously, the Steri protocol and the cold chain has several functions, like fruit preservation and the elimination of pests (such as the FCM, medfly and Natal fruit fly). It is, however, also widely recognised that the protocol may cause CI, because of the excessively low temperatures that the fruit are exposed to (Hordijk, 2013).

CI is temperature and time dependent, in other words how long the citrus are stored and at what temperature it was stored. It also depends on the species, the specific cultivar and the environment of cultivation (Lyons, 1973). "For most fruit, there is a threshold temperature and time interaction that will be influenced by region and cultivar" (Hordijk, 2013). Navel oranges' susceptibility to CI, for example, are influenced by cultivar, micro-climate, harvest date, fruit size and rind colour (Hordijk, 2013). In Hordijk's (2013) study on CI, which was also conducted from Citrusdal, she found that the highest frequency of CI came from the coldest area of the region. This was concurrent with the available literature at the time and indicates that a colder climate may increase the possibility of CI. Cases of the defect appeared to be less frequent during the middle of the harvesting window. Internal maturity, however, seemed to have no effect on citrus' susceptibility to CI.

Certain citrus cultivars are more susceptible to CI than others. Mandarins for example, are more susceptible than navel oranges, which in turn are more susceptible than Valencias. The industry reports that lemons and grapefruit look to be more susceptible than any of the abovementioned (Hordijk, 2013). Because these cultivars are chilling sensitive, they tend to have shorter storage lives. This makes them more difficult and riskier to export, as they obtain damage easily. CI in citrus fruit differs from other fruit, because citrus fruits have a thick rind that contains unique phytotoxic oils (Hordijk, 2013).

CI is often confused with freezing injury (FI), but they are two different defects. CI is a condition that damages the rind of the fruit and is a result of cold storage temperature. CI usually occurs from just below 0 to 10 ºC. FI, on the other hand, only occurs at sub-zero temperatures and entails the formation of ice crystals on the fruit (Hordijk, 2013).

It may take several weeks for symptoms of CI to emerge. In other fruit types and at different temperatures, it can take a mere couple of hours. Bananas are a good example (Lyons, 1973). Symptoms in citrus fruit are distinct and easy to detect. They include both internal and external deviations. Internally, common CI symptoms are discolouration and browning. External symptoms are water-soaking, abnormal ripening, accelerated decay and surface lesions (Lafuente *et al.*, 2005). Fruit that have suffered from CI have been found to develop pit-like depressions in the flavedo (usually brown) as well as non-depressed extended areas, which are bronze in colour (Also known as superficial scald). Generally, the main cause of CI symptoms is the death of cells (Hordijk, 2013). This broad spectrum of symptoms has made CI one of the more complicated citrus defects, as they develop for different reasons and deviate between cultivars (Lafuente *et al.*, 2005).

Lafuente *et al.* (2005) propose that companies transport each citrus cultivar under its own unique cold treatment conditions, because cultivars have different levels of susceptibility to CI. In most cases, however, this is not possible, because of practical reasons and protocols like Steri. Certain practices can significantly reduce the incidence of CI. The most effective being the application of Thiabendazole (TBZ) during the waxing process. Waxing alone reduces the occurrence of CI, but when applying TBZ to the mixture, CI prevention was the most effective. Successfully reducing CI to a minimum requires a multi method approach, which stretches through pre – and post-harvest (Hordijk, 2013).

2.8.3.2 Granulation

Granulation is a citrus disorder where the juice sacs become hard, too large and greyish in colour. Granulated citrus has little free juice. The disorder has different names, but the most common one globally is granulation (Sharma, Singh & Saxena, 2006). Most citrus cultivars are prone to granulation, but some are more susceptible to it than others are. Sweet oranges and mandarins are the most susceptible cultivars (Sharma *et al.*, 2006). Delayed harvesting proves to be the most common cause of dry citrus fruit. This happens when the fruit remains on the tree for too long after the ripening phase. Citrus that are harvested later in the season are generally more prone to granulation than those harvested in the earlier parts of the season (Sinha, 2017).

As mentioned in the previous sub-section, improper irrigation and nutritional planning can lead to granulation. Research discovered that a lack of water and excessive nitrogen are some of the main nutritional causes of granulation. Nitrogen encourages citrus fruit to grow rapidly and too much of it may cause the foliage to grow at the expense of the fruit (Sinha, 2017). Weather may also have a profound influence on citrus granulation and is unfortunately, out of farmers' control. Both excessive heat and cold can cause granulation. During extreme weather conditions, the fruit will suffer while the tree attempts to survive (Sinha, 2017).

Rootstock variation also has an influence on granulation. Previous research has shown that cases of granulation are more common with vigorous rootstocks than with slower growing rootstocks. Granulation also seems to be more common with larger citrus cultivars and less prominent in smaller cultivars. Younger trees seem to have a higher tendency to produce granulated citrus than older trees (Sinha, 2017).

2.9 REGULATORY ORGANISATIONS

The citrus industry is strictly regulated by several international organisations and SA as a country is a signed member of the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures as well as the International Plant Protection Convention (Carstens *et al.*, 2012). Therefore, in SA, there are authorities that regulate the industry and ensure that the country complies with the standards that it needs to meet.

The two main regulatory bodies that have a major influence on cold chain practices concerning citrus exports to the USA are the South African Department of Agriculture, Forestry and Fisheries (DAFF) and the United States Department of Agriculture (USDA), both have some important sub-divisions. These organisations regulate the exporting industry by formulating and implementing rules and standards that stipulate how exporters should operate. They also perform regular inspections to ensure that the industry operates as stipulated. The following sub-sections discuss both of these sub-sections.

2.9.1 THE SOUTH AFRICAN DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF)

DAFF is SA's governmental body in charge of farming, forestry and commercial fishing – as the name suggests. The aim of the department is to ensure that all concerning parties adhere to the legislation that was formulated by the South African government (DAFF, 2018).

DAFF is responsible for all phytosanitary inspections, along with USDA-APHIS. The USDA and DAFF are also responsible for forwarding all interception data to the relevant parties. They are responsible for monitoring orchards, pack houses and inspection depots in tandem (National Department of Agriculture, 2008).

Furthermore, DAFF is responsible for ensuring the implementation of the Good Agricultural Practices (GAP) legislation. It also has the responsibility of registering all production units (PUC's) and pack houses (PHC's), scheduling inspections, identifying insects, pests and diseases, and developing and managing programs, records and statistics (National Department of Agriculture, 2008). It is the highest departmental entity in terms of agriculture, but has appointed the PPECB as a sub-division that ensures that citrus destined for local and foreign markets meet the requirements for consumption and exporting (PPECB, 2017).

2.9.1.1 The Perishable Products Export Control Board (PPECB)

The PPECB is an independent organisation that provides quality certification and cold chain management services. The board's services cover a broad spectrum of products, as it regulates all perishable products exported from SA. The main purpose of the PPECB is to enhance SA's exporting credibility and competitiveness. Furthermore, the PPECB is constituted and mandated by South African law and delivers regulatory services and inspections under instruction of DAFF (PPECB, 2017). These services include the following (PPECB, 2005):

- Registering all cold storage facilities used for exports from SA.
- Inspecting the cleanliness and technical functionality of all refrigerated trucks, vessels and containers used to transport South African fresh produce.
- Pre-trip inspection to ensure that reefer containers are fully funtional and free of defects.
- Inspecting cleanliness and technical functionality of conventional vessels. Cooling equipment, temperature monitoring and control devices are also inspected as well as shipping compartments.
- Random temperature checks at hinterland cold stores during precooling, storage and before loading perishables into containers.
- Temperature checks on arrival in the port, during precooling, recooling and cold storage before shipping. This is to ensure that fruit is shipped at the correct temperature.
- Regular auditing of container ventilation systems for temperature setting, adherance to protocols and functionality of the cooling unit.
- Product temperatures at time of departure to ensure the correct loading temperatures.
- Instructing the shipping Master on the protocols for optimum carrying conditions as agreed upon between the PPECB and the exporter.
- Monitoring product temperature during the voyage to regulate carrying conditions and appliance of special protocols, if required by importing country.
- Accurate record keeping to assist with crisis management. Regional Managers must inform all applicable parties if any problems or irregularities occur.

2.9.2 THE UNITED STATES DEPARTMENT OF AGRICULTURE

The USDA operates on behalf of the US government. It regulates and inspects all agricultural products that are destined for US markets. The USDA's functions include quality assurance, and pest and disease control.

2.9.2.1 Animal and Plant Health Inspection Service (APHIS)

The USDA consists of 29 agencies, with APHIS overseeing citrus imports. APHIS Plant Protection and Quarantine (PPQ) regulates the importation of plants and plant products (including citrus) by inspection. Inspection occurs at two main points – the port and cold stores. If there is any evidence that raises suspicion regarding a consignment of citrus, it will be rejected (USDA, 2017).

2.9.3 EFFECT OF POOR COLD CHAIN MANAGEMENT

Irregularities during cold chain practices negatively impacts exporters and farmers, because the PPECB or USDA may reject a shipment that does not meet the required standards (PPECB: Cold Chain Management, 2017). The PPECB and USDA are regulatory bodies that ensure perishables destined for exportation from SA are in an acceptable condition. They offer services that are important to cold stores, importers, logistical service providers (LSP's) and exporters (PPECB: Cold Chain Management, 2017).

The PPECB conducts numerous tests on a cold store before approving it as a PPECB-verified cold store. This verification assures all the relevant parties that the products leaving the cold store are safe to consume (PPECB: Cold Chain Management, 2017). Furthermore, the PPECB assures importing entities that the products meet the standards set in place for that specific destination. They also regulate and inspect LSP's equipment, and ensure that proper cold chain practices take place throughout the cold chain (PPECB: Cold Chain Management, 2017).

According to the PPECB, proper cold chain management plays a substantial role in reducing the occurrence of (PPECB, 2005):

- Fruit waste, because of various rots caused by fungal infections.
- Weight loss caused by a decline in fruit moisture. Loss of moisture leads to wilting and will give the fruit a worn out or even shrivelled appearance.
- Excessive ripeness leading to the loss of texture, juiciness, flavour and taste. Decreasing acid and sugar content will result in tasteless fruit or even an off taste.
- Loss of cosmetic appearance. Fruit that lose lustre and appear less fresh.

2.10 PREVIOUS STUDIES

This section summarises previous studies that relate to this thesis. As mentioned earlier, several studies in the past specifically evaluated the temperature profiles of fresh fruit in the cold chain. Stellenbosch University conducts extensive research on the influence of temperature on fruit quality. Therefore, this section contains various studies conducted by members and students from Stellenbosch University's Department of Logistics.

Khumalo's (2017) research specifically recommended this study. She investigated the occurrence of temperature breaks during the entire export cold chain of Navel oranges. Her data came from two vessels, namely the Santa Lucia and Regal Bay. The study covered the entire export chain, from the orchard to the consumer in the USA, but, unfortunately, a significant number of devices disappeared.

The study's conclusion recommends future research, retrieving the devices at the Port of Cape Town and, thereby, only investigating the initial stages of the cold chain. Assisted by two Honours students, Khumalo (2017) identified several inefficiencies in the initial stages of the Navel orange cold chain from Citrusdal. She recommended future research with a broader scope and larger sample.

The study discovered that temperature spikes occurred at various points along the Navel orange export chain. After the drenching process, several temperature spikes occurred because of exposure to direct sunlight. Khumalo (2017) recommended the construction of shaded areas under which to store the citrus after drenching. Temperature spikes occurred during transportation from the drenching area to the pack house, also due to weather exposure.

Furthermore, there were temperature spikes during transportation from the pack house to the cold store. The researchers suspected that airflow in the tautliner trailers was the main cause of these temperature spikes, allowing the day temperatures to heat up the citrus.

They identified the inspection segment as one of the main problem areas. Inspection takes place at room temperature and can be a lengthy process. This regularly causes difficulties with maintaining the citrus fruits' temperature. Khumalo (2017) suggested the regulation of inspection room's temperatures, as is done with pack houses. This will allow the fruit to maintain the cold rooms' temperature more efficiently. Farmers and exporters usually keep pack house temperatures between 18-25 ^oC.

Prominent temperature breaks occurred during the loading phase. During loading, Company K's processes allowed too much time between the pallets' removal from the Steri chambers and the actual loading process. As with the inspection phase, the citrus could not maintain the temperatures from the Steri chambers efficiently. During the inspection and loading phases, the most likely to experience temperature spikes and breaks were the top cartons. During the other phases (transportation and the sea leg), the middle cartons were more vulnerable.

Khumalo (2017) concluded that temperature spikes and breaks occurred during the SA part of the export chain, but that the temperature stabilized after the Steri protocol's initiation. The main reasons for temperature spikes and breaks were exposure to sunlight, transport delays, exposure to weather elements and inspection delays.

In 2013, Haasbroek investigated the occurrence of temperature breaks from pack house to vessel during the summer window of South African fruit exports. Her results indicated that companies neglected proper cold chain practices in order to shorten the length of time that fruit spent in the cold chain, thereby leading to higher export volumes over shorter timeframes. The researcher used personally gathered data alongside historical data that an assisting company provided. She concluded that too many temperature breaks were occurring during the South African part of the journey, with an emphasis on the port segment - most of the breaks occurred during the loading and unloading of containers. She recommended similar future research on different fruit types, with an end goal of eliminating the future occurrence of temperature breaks.

In that same year, Freiboth *et al.* conducted a case study to investigate the same phenomenon. The study aimed to highlight some potential problem areas in the cold chain by mainly looking at historical data. He conducted an additional experiment on a shipment of apples, to determine temperature distribution inside a container.

Their results showed that 65% of the containers experienced a temperature break at the port segment of the journey, while only 8% experienced temperature breaks during the transport leg. This is concurrent with Haasbroek (2013), who also found that a significant number of temperature breaks occurred at the port. They also identified that 60% of all the temperature breaks occurred between 08:00 and 17:00, while a quarter occurred between 12:00 and 15:00. This is worrying, since the day is at its warmest during that timeframe. Therefore, a temperature break occurring during that period will have the most profound effect on fruit quality.

With the apple trial, they found that the ambient temperatures were clearly higher at the back of the container, where the gen-set delivers the cold air, than at the front. Furthermore, the results showed that the pulp temperatures inside a container are clearly higher than the ambient temperature, meaning that the container may not cool the fruit down to the temperatures stipulated on the gen-set. The pulp temperature showed a different trend regarding temperature breaks, since the ambient monitors seemed to react more prominently to increases in temperature.

While the temperature breaks had less influence on the pulp temperature than on the ambient temperature, the pulp temperature took longer to recover from these breaks. They determined that fruit respiration was the most probable cause for the pulp temperature's delayed reaction to temperature changes. After a break at the port, the ambient temperature inside the container took 5 h and 25 min to reach 0.5 °C, while the pulp temperatures only reached the same level after 14 h and 45 min.

They concluded that the variance of ambient temperatures in different parts of a container is a concern and could have a negative impact on fruit quality. The same is the case for the difference between pulp and ambient temperature. They also found that the average ambient carrying temperature was acceptable during the entire voyage, but that the average pulp temperature was significantly above the prescribed level of -0.5 °C, which is a worrying discovery. Freiboth *et al.* (2013) state that improving cold chain practices would have a two-fold advantage. It would improve fruit quality, leading to higher earnings, and reduce losses, leading to better yields. Such improvements would help to improve SA's competitiveness.

Goedhals-Gerber *et al.* (2015) studied the effect that logistical activities and infrastructure have on these temperature breaks. They conducted their trials on South African table grapes, summer pears, apples and plums that were destined for the European Union (EU) and United Kingdom (UK) markets. The mode of transport was refrigerated containers. The aim of their research had many similarities with the aim of this study, which was to identify temperature breaks along the cold chain, as well as their duration and magnitude.

Once again, the results indicated that a significant number of temperature breaks were occurring during the South African part of the cold chain, with the majority happening during the switchover from the truck to the cold store. When compared to historical data, the research showed positive results, concluding that the number of temperature breaks experienced at the Cape Town Container Terminal (CTCT) declined after the implementation of the new NAVIS and Refcon systems.

The data analysis for the 2011/2012 season showed that only 9.2% of the containers did not experience temperature breaks, while 31.1% had at least one, 24.5% had two, 19.9% had three and 8.7% experienced up to four temperature breaks. After collecting these results, the researchers were able to identify which areas of the cold chain needed in depth investigation, which happened during the 2012/2013 season.

For the 2012/2013 season, only 11% of the containers did not experience temperature breaks. Almost half (49%) experienced one temperature break, of which many lasted for longer than a day. A quarter of the containers experienced two temperature breaks. Like with the previous studies, most of the abovementioned breaks occurred during the interface between the truck and the port. Furthermore, nine more containers experienced three temperature breaks while another eight experienced four temperature breaks. For the two remaining containers in the data set, the temperature never went below the 2 °C mark.

Before the Port of Cape Town implemented the NAVIS and Refcon systems, 47.17% of the temperature breaks occurred while the containers were at the port. In the following season, after they implemented the systems, most of the temperature breaks occurred in the trucking segment (45.9%). The main problem area in the cold chain proved to be the interface between the cold store and container loading segments (when the pallets are loaded into containers). For this season, only 32.8% of the total breaks occurred while the containers were at the port, which is considerably less than for the previous season (when the NAVIS and Refcon systems was not yet implemented).

The study concluded that a significant number of temperature breaks in the cold chain occurs during the South African segment. Furthermore, they elaborate that there are logistical inefficiencies in the South African fruit export industry that lead to these temperature breaks. In other words, farmers and exporters' concern about the significant fruit losses each season are indeed because of temperature breaks in the along the cold chain. The fact that these breaks are still regularly occurring sadly over-shadows the success of the NAVIS and Refcon systems in reducing temperature breaks at the port, because they should not be happening at all.

The group of researchers proposed the installation of air locks at the cold stores to reduce the amount of cold air that escapes during loading and unloading. This is an expensive solution, though. They also proposed the use of further research to identify the specific causes of the temperature breaks, enabling the direct addressment of the problem. Added to this, an expanded analysis should include the operations from the farm and pack house on the South African side, as well as the sea leg, port operations and operations until the fruit arrives at the retailer on the destination side.

The final study that is discussed in this section, was done by Valentine & Goedhals-Gerber (2017). The goal of their research was to determine the influence that logistical activities during the first 48 hours of an apple supply chain have on the quality and yield of the fruit. The apples that they used were cultivated in the Ceres region of the Western Province. Like this study, they utilised two different cultivars and gathered data from three separate farms, which improved the representative power of the research. iButtons® were used to measure pulp and ambient temperature, with recordings being taken every minute for the first 48 hours of the supply chain.

Their results showed that time of harvest and time of cooling (to remove field heat) both played a significant role in ensuring that the apples obtained the prescribed temperature profile within 48 hours. Effectiveness and efficiency during picking (preferably between 07:00 and 09:00) alongside immediate transportation to storage and cooling facility following picking was also identified as playing a vital role in ensuring the apples were ready for exporting in time. Furthermore, they state that it is important that farmers consider their logistical processes in the first 48 hours of the supply chain carefully, as it could assist them to achieve economic advantages.

They found that leaving bins with apples in the sun, even for a short while, negatively impacts fruit quality. They also determined that the ambient temperature of apples cool down considerably faster than the pulp temperature. This is because of the respiration of the fruit, as previously mentioned, and emphasises the importance of placing fruit in cold storage shortly after their harvest, in order to cool the core down as soon as possible within the prescribed timeframe.

2.11 INTERNATIONAL BEST PRACTICE

Freiboth (2012) developed a best practice guide for a deciduous fruit cold chain. The basic structure of the guide may be applicable to a citrus cold chain. He stated that certain temperature breaks are avoidable, while others are unavoidable. For example, leaving fruit to stand outside in the sun is avoidable by constructing shaded areas. However, loading citrus from the Steri chambers onto the ship must happen at some point, and leads to unavoidable temperature breaks. Therefore, he concluded that exporting parties should eliminate avoidable temperature breaks and minimise unavoidable temperature breaks and their impact.

The packing process is an example of an unavoidable break in deciduous fruit cold chain. It is not a temperature break in a citrus cold chain, but it does delay the start of the cold chain. Therefore, this process should happen as quickly and efficiently as possible, which allows the fruit to enter the cold chain quicker.

An example of pack house innovations that reduce packing times is a new cold store in Ceres, built by Ceres Fruit Growers. The pack house's floor is sealed and sloped to minimise water build-up. This is safer and more hygienic and allows personnel to operate at a higher efficiency (Freiboth, 2012). The ambient temperature is minimised by using insulating materials on the walls. A high roof with a ventilation system also lowers the pack house's temperature. Water-intensive packing lines reduce fruit damage, which shortens the inspection process. All the above-mentioned innovations help to keep unavoidable breaks in the cold chain at a minimum.

Freiboth (2012) states that improving SA's cold stores, will help to minimise breaks in the cold chain. This includes upgrading existing cold stores to modern standards as well as expanding the country's current cold store capacity. Adding additional intake loading bays at the port will reduce congestion and shorten the time before the citrus enters the cold chain.

Completing the loading process must happen as quickly and efficiently as possible to reduce the amount of time the citrus are not under refrigeration. Furthermore, the establishment of a good cold chain culture amongst the SA trucking community is crucial. This includes educating truck drivers on the importance of keeping a secure cold chain and the repercussions of failing to do so.

During the peak season, wind becomes a major concern at the Port of Cape Town. It is impossible to reduce the occurrence and strength of wind, but it is important to have systems in place that reduce the impact thereof. Utilising equipment with a higher wind threshold and working night shifts (because the wind is usually weaker at night) are examples of possible solutions. Ensuring that shift changes happen as quickly as possible can further reduce the occurrence of unavoidable breaks.

Capturing and storing the temperature data can help to identify and eliminate avoidable breaks and minimise unavoidable breaks. Therefore, Freiboth (2012) recommended that the temperature data of all shipments are stored, not just the data that contain breaks. It is important that exporters and service providers collaborate so that the technology and software that are utilised stay up to date.

Having the newest equipment would be useless without the establishment of a good cold chain culture amongst the various role players in the SA fresh fruit export cold chain. This entails that every entity understands the importance of maintaining a dependable cold chain. Establishing local cold chain centres and initiatives is a step in the right direction. Examples are the USDA Cold Chain Improvement Initiative, the Asian Cold Chain Centre and the Georgia Tech Integrated Food Chain Centre (Freiboth, 2012).

Haasbroek (2013) also developed a cold chain best practice guide for table grapes in SA. Some of the guidelines are to harvest the fruit in lower temperatures, not leaving them standing in the orchard after harvest, off-loading in the shade and starting cold storage as soon as possible.

She also suggested keeping pack houses between 18 – 25 ºC and using insulated roofs to maintain these temperatures. Lighting should be adequate, but should not lead to excessive heat in the pack house. Furthermore, cold store doors should stay closed and only opened, if necessary. They should also contain strip curtains to keep out excess heat. The loading process should happen quickly and smoothly. Haasbroek (2013) recommends having designated staging and loading areas. She also recommends the use of airlock loading bays, but this may not always be possible as it is expensive.

2.11.1 TECHNOLOGICAL ADVANCEMENTS

Cold chain logistics is dependent on various forms of technology in order to function properly. In modern times, technological advancements happen at a rapid pace, with exciting new developments like blockchain technology and the internet of things (IoT) enabling businesses to enhance their competitiveness significantly. Blockchain technology and the IoT are only in their beginning stages and are sure to change the way companies conduct business in the future. The logistics industry is no different and these technological concepts offer significant advantages to the entire supply chain. The rest of this section is dedicated to elaborating on three of these concepts, namely blockchain technology, IoT and Radio-frequency identification (RFID).

2.11.1.1 Blockchain technology

Blockchain technology attracts substantial interest from various industries, including logistics. Currently, however, the financial industry is at the forefront of implementing this concept, especially regarding crypto currencies like Bitcoin and Ethereum. The single most ground-breaking advantage that blockchain technology offers is an all-new level of security, being almost impossible to tamper with (Nofer, Gomber, Hinz & Schiereck, 2017).

An example of blockchain technology developments in the logistics industry is a recent development that Walmart are undertaking. This entails implementing the concept into their fresh food supply chain processes, which will enable them to track batches of produce in real time. The idea behind this development is to decrease the number of annually reported food poisoning cases. Blockchain technology will enable the company to identify the infected batch of food instantly, so they can warn the specific customer that bought the product in time (Nofer *et al.*, 2017).

Another prominent concept that has come to surface through the introduction of blockchain technology is smart contracts. Smart contracts are digital contracts that are encrypted by the blockchain that allows for the replacement of third parties like lawyers and consultants that would have been required otherwise (Nofer *et al.*, 2017).

Blockchain and smart contracts are still in their developing stages in the field of logistics and developers need to address various problems with the concept before the industry fully implements blockchain technology (Shanley, 2017). For example, a big current issue is the accurate input of data into the system. A blockchain usually involves two or more participants that make use of the chain. Human error may lead to incorrect data capturing and rectifying mistakes in a blockchain involves complicated processes (Shanley, 2017).

2.11.1.2 Internet of things

IoT is a collective name for a broad network of wireless sensors and devices that companies use to track products and assets through the internet and private networks (Pelino & Gillett, 2016). They include devices that monitor the environment and temperature; remotely monitored optical sensors; and recently, sensors that are wearable, edible and implantable to monitor biological functionalities (Caro & Sadr, 2019). IoT has a major advantage regarding channel integration, because of its ability to rebalance supply and demand.

With the IoT, RFID technology (discussed in the next section) allocates a digital identity to individual objects, allowing producers to keep track of individual products through-out the SC (Tu, Lim & Yang, 2018). IoT allows businesses to enhance their operations in tandem with their trade partners and suppliers by integrating SCs. IoT is substantially advantageous for companies that seek to improve the responsiveness and agility of their SC by making real-time visibility possible (Tu *et al.*, 2018).

IoT has significantly improved 3PL's and carriers' product monitoring abilities. It has helped these companies to address data gaps and reduce product waste by keeping track of products in real-time (Shanley, 2017). FedEx, for example, have implemented a program called Sensaware in their healthcare and pharmaceutical department that monitors products' location, temperature, light exposure, relative humidity, shock thresholds and barometric pressure constantly, so that a product can be isolated when a device discovers an irregularity (Shanley, 2017). In the majority of cases, companies recover the investment required to implement IoT into its functions within a year, because of the technology's enabling abilities (Caro & Sadr, 2019).

2.11.1.3 Radio-frequency identification

RFID, IoT and blockchain technology are inter-related, since both of the latter incorporate RFID into their functioning [Caro & Sadr (2019); Zhao, Dai & Zhou (2013)]. RFID is a technology that captures digital data using readers (sensors, recorders, etc.) that connects to an individual object by means of a tag or "label." Special software then transmits the data to concerned entities via radio waves. Experts often compare RFID to barcoding because of its uniqueness and data-capturing nature (AB&R, 2019). The biggest difference between RFID and barcoding is that RFID is not limited to a line of sight distance in order to download data; personnel can scan an item from several feet away.

RFID tags come in two forms: passive and battery powered. Passive tags use radio wave energy to function while battery powered tags are embedded with small batteries to relay information (EPC-RFID INFO, 2019). RFID allows producers, exporters and carriers to track the entire life-cycle of a product from its origin to its destination (Yan & Lee, 2009). As with the two previous systems, RFID is real-time, allowing constant quality management.

2.12 CONCLUSION

By studying the existing literature, the researcher gained significant insights about the initial operations of a conventional citrus supply chain. It is evident that there are several unanswered questions regarding the efficiency of this process and that answering them will benefit the industry. Cold chain logistics is a substantial industry that has had a profound influence on global trade by significantly expanding the range of products that are exportable.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

Chapter 3 explains the approach that the researcher followed while conducting the study. It starts by explaining the initial planning and required equipment. Subsequently, it explains the planning and processes behind data collection, software used for data analysis and the data analysis itself. The final section is a conclusion of the chapter.

3.2 PLANNING

As mentioned in Chapter 1 and Chapter 2, Khumalo (2018) conducted a similar study on Navel oranges in 2018, but experienced significant difficulties while attempting to return the iButtons® from Newark, New Jersey. As a result, the researcher decided to conduct a similar study [as recommended by Khumalo (2018)] that ended at the Port of Cape Town, only analysing the South African leg of the export chain. This allowed for personal retrieval of the iButtons®, ensuring a significantly higher retrieval rate. Khumalo's (2018) study only analysed the temperature data of Navel oranges from one farm in Citrusdal, referred to as Farm B in this study. To broaden the scope, this study planned to investigate citrus from three different cultivars and two different farms. Eventually, due to unforeseen circumstances, the researcher only managed to collect data from two cultivars.

Prof Daan Nel, a statistician at Stellenbosch University's Centre for Statistical Consultation, assisted the researcher with the sampling process. Prof Nel determined an ideal sample size of 216 devices through a power analysis on Statistica®. Unfortunately, as mentioned earlier, the researcher only collected data from two cultivars (Clementines and Navel oranges), because insufficient fruit sizes forced the season to an early close. The missing cultivar did not affect the study's power, because it meant the exclusion of a dimension from the power analysis. It did, however, reduce the scope. The exclusion meant a total probe count of 144 temperature monitoring devices.

3.2.1 QUALITATIVE DATA

The study consists of both primary qualitative and quantitative data, as well as secondary qualitative data. Primary qualitative data came in the form of personal conversations and informal interviews with the various role players throughout the SA leg of the export chain, while the literature review consists of secondary qualitative data.

3.2.2 QUANTITATIVE DATA

The primary data source for this study was the temperature data collected through the temperature trials, which is quantitative data.

3.3 ETHICAL CONSIDERATIONS

3.3.1 PERMISSION

Company J signed a written document that permitted the researcher to conduct the study. With this document, they granted the researcher access to the temperature data contained within the data analysis. All the parties that participated in the study granted verbal permission and were aware of the document that Company J signed. These include interviewees and personal conversations.

3.3.2 CONFIDENTIALITY

The researcher agreed to keep all participants confidential by using pseudonyms. This ensured that the participants were protected from any harm, abuse or harassment. These pseudonyms are: Company J, Company K, Farm A and Farm B.

3.4 SAMPLING

After determining a sample size of 144 devices, the researcher selected the two cultivars – Clementines and Navel oranges – by utilising the judgement sampling technique. The reason for using judgement sampling was mostly because of the structure of the harvesting season and cultivar availability. Most cultivars are only available for a segment of the season. Therefore, data collection occurred based on the availability of produce.

3.5 EQUIPMENT

This study required only basic equipment for data collection. Company J sponsored the temperature monitoring devices, named iButtons®. At the farm, the researcher used a pocketknife to cut the fruit and a pair of scissors to cut the duct tape with which they stuck the devices (in)to the fruit. Furthermore, the iButtons® required protection from the moisture inside the citrus, which came in the form of isolation tape. The isolation tape also enabled the researcher to remove the devices easily. This was the only equipment required to conduct the study.

3.6 DATA COLLECTION

The researcher collected data from four consignments distributed over two cultivars, namely Clementines load one, Clementines load two, Navels load one and Navels load two. Each consignment consisted of 36 devices, 18 measuring pulp temperature and 18 measuring ambient temperature. Each pallet contained two probes in the bottom cartons, two in the middle cartons and two in the top cartons. For the transportation stage, the forklift drivers received instructions to load two pallets in the front of the front trailer, two in the back of the front trailer and the other two in the back of the rear trailer. This ensured an even probe distribution throughout the trailers.

The researcher personally travelled to the farms to probe the fruit. Cold Chain Thermo Dynamics (special programming software) created the possibility to predetermine the time that the iButtons® started recording. The researcher probed the fruit before this predetermined time, so that the devices all recorded temperature data from the moment they activated. The researcher (along with the assistance from and Honours student) made a small incision in the citrus in which they inserted the probes to measure the pulp temperature. To measure the ambient temperature, they stuck the probes on the outside of the citrus. For both pulp and ambient temperature, they fastened the probes with duct tape.

At the end of the SA leg of the cold chain, the researcher travelled to the Steri chambers in the port at Company K to collect the devices. Shortly before loading commenced, the researcher entered the Steri chambers with a bin bag to remove the citrus from their respective boxes. During their insertion at the pack house, the researcher cut a small flap in the boxes, which made the citrus more accessible. This enabled the researcher to remove the fruit easily and efficiently, without wasting Company K's time.

The official retrieval rate after the exclusion of device malfunctions was 130/144 devices or 90.28%. This number is significantly higher than Khumalo's (2018). Of the 14 omitted devices, only one is due to a lost device, the other 13 are due to malfunctions. Overall, the data collection phase was successful, with a sufficient number of data points – 73 457 in total.

3.7 SOFTWARE

3.7.1 MICROSOFT SUITE

Firstly, qualitative typing for this study occurred on Microsoft word. Word was also the main program for designing and constructing tables. Furthermore, Microsoft Excel was the basis for data storage for this study. Cold Chain Thermo Dynamics (CCTD), which has an Excel exporting option, extracts the data from the iButtons®. After finishing the data extraction, the researcher combined each individual iButton's® data into a single Excel file. They also utilised Excel to construct various graphs and figures.

3.7.2 COLD CHAIN THERMO DYNAMICS

CCTD is the program that preconfigures the iButtons® and extracts the data once they are removed. The data extraction function will also turn the iButton® off. The researcher pre-set the iButtons'® activation time on CCTD before they departed for data collection. CCTD has an option to export the data to an Excel file.

3.7.3 TABLEAU

Tableau is a data visualization program that enables users to present data in a user-friendly manner. After modifying the data, the researcher utilised Tableau to create time-series line graphs and box-and-whisker plots. The line graphs illustrate the temperature profile of the citrus by plotting the average temperature of all the devices over time from right to left. The box-and-whisker plots illustrate the data's dispersion as follows. At the top (furthest end of the whisker) is the maximum. Below that (top value of the box) is the upper quartile. Below the upper quartile (middle value of the box) is the median. Below that (bottom value of the box) is the lower quartile. The final value on the plot, which is at the end of the bottom whisker, is the minimum.

3.7.4 STATISTICA

As mentioned previously, Prof Daan Nel from the Centre for Statistical Consultation used Statistica's power analysis function to determine the sample size of 144 devices.

3.8 VARIABLES

3.8.1 TEMPERATURE

This study measured temperature in degrees Celsius (°C). Degrees Celsius is the unit of measure and expresses the presence of heat or the absence thereof.

3.8.2 DATE

The dates in this study identifies the day of the month for the calendar year of 2018, which is the year in which the researcher collected the data. The study expresses date in the following format: DD/MM/YYYY where D = day, M = month and Y = year.

3.8.3 TIME

Time represents the time of day on a specific date. The iButtons® recorded temperature data every 30 minutes, in other words twice an hour. The study expresses time in the following format 00:00 or hours: minutes.

3.8.4 STAGE

The cold chain consists of various stages and the study documents the results per stage. These stages are the outside stage, degreening stage, pack house/ transportation stage; cold storage stage and Steri stage.

3.9 DEFINTIONS

3.9.1 TEMPERATURE BREAK

For the purpose of this study, the definition of a temperature break is as follows: *anytime the temperature rises by 2°C or more, for 90 minutes or longer during the export cold chain.*

3.9.2 TEMPERATURE SPIKE

For the purpose of this study, the definition of a temperature spike is as follows: *anytime the temperature rises along the export cold chain of the citrus.* The study refers to temperature spikes when a temperature increase, that did not meet all the criteria of a temperature break occurred in the export cold chain. In addition, it refers to temperature spikes in certain individual cases, like the degreening stage, where the temperature is supposed to increase, but only up to a threshold of 25°C. If the temperature increased above this threshold, it qualified as a temperature spike.

3.9.3 RISK OF CHILLING INURY

For the purpose of this research, the study refers to fruit being at risk of chilling injury when the temperature met the following criteria: *anytime the temperature is equal to, or drops below, the citrus chilling injury threshold of -1.5°C.*

3.10 DATA ANALYSIS

The data analysis followed a deductive approach. The specific research design was a case approach with an exploratory nature. After extracting the data with CCTD, the researcher combined all the data into a larger single Excel file. Each consignment had its own individual Excel spreadsheet. This was necessary to ensure that the data was compatible with Tableau.

After cleaning the data, the researcher used Tableau to draw time-series line graphs and box-and-whisker plots. Each chapter in the data analysis explains the discoveries of an individual consignment, elaborating on the line graphs and box-and-whisker plots. The data analysis identifies each individual temperature spike/ temperature break and explains where it occurred. Following the data analysis, an interpretation chapter explains the reasons for the temperature breaks and a recommendations chapter provides possible solutions for the problems detected throughout the export cold chain.

3.11 CONCLUSION

The data analysis was successful and delivered significant results. Role players in the export chain of Clementines and Navel oranges from the Citrusdal region may possibly improve their international competitiveness by assessing the problems that the study identified.

CHAPTER 4: DESCRIPTIVE DATA ANALYSIS

4.1 INTRODUCTION

This chapter is dedicated to analysing, interpreting and graphically illustrating the data collected in the temperature trials conducted for this research. After consulting two experts from the Centre for Statistical Consultation and the Department of Logistics, the researcher utilised Statistica® and Tableau® to construct the graphs within the following sub-sections. These graphs aim to assist readers in understanding the results.

The rest of the chapter explains the stage breakdown of the study and analyses the four consignments of citrus per stage, elaborating on central tendency, dispersion, discrepancies, irregularities and temperature spikes/breaks that were identified along the cold chain.

4.2 COLD CHAIN BREAKDOWN: FARM A AND FARM B TO COMPANY K

This section provides an explanation of how the researcher and relevant parties split the cold chain into different sections (stages). It also explains what each of these stages entails and how they work. The study's data collection stopped at Company K's Steri chambers right before the pallets were loaded onto their respective vessels. Cold chain processes can vary from farm to farm, but Farm A and Farm B implement the same cold chain processes.

4.2.1 OUTSIDE STAGE

Farm A and Farm B start harvesting in the morning as soon as the citrus is dry from the dew of the previous evening. As mentioned earlier, harvesting citrus when they are wet has a negative influence on the quality of the fruit. Workers move through the orchards and selectively pick fruits that are ripe. They repeat this process a couple of times for an orchard as the citrus fruits do not ripen simultaneously. The workers pick the citrus from the trees using clippers and place them in picking bags. Once a bag is full, the worker empties it into a bin on a tractor trailer. Either a truck or tractor, depending on the distance, transports the filled bins to the nearest drenching facility as soon as possible.

The iButtons® cannot tolerate the chemical substances in the drenching fluid, therefore, the researcher probed the fruit directly after the drenching process. This led to the exclusion of the phases prior to drenching. These processes are short and measuring them would have significantly complicated the farms' operations. Therefore, the researcher decided to exclude the processes prior to drenching from the research.

Farm A used the pack house drench for all the consignments in this study. After the citrus underwent the drenching process, the researcher immediately probed the fruit with the iButtons® and secured the devices with duct tape. Before entering the degreening chambers, the fruit stood outside on the farms' packing premises for varying durations of time.

4.2.2 DEGREENING STAGE

Both farms in this study utilise the conventional degreening process described in Section 2.1.5 of the literature review. This stage starts when the citrus enters the degreening process and the doors of the chambers close. Workers fill the room by stacking the bins on each other with forklifts. The degreening stage ends when all the citrus are out of the chamber. After the degreening stage, a representative of Farm A removed the devices from the citrus and kept them in an office until Farm A/ Farm B confirmed suitable packing dates to commence the next stage – pack house/transportation.

4.2.3 PACK HOUSE/ TRANSPORTATION STAGE

After Farm A/ Farm B confirmed packing dates, the researcher returned to the respective farms to place the iButtons® for the pack house/ transportation stage. Inside the pack houses, Farm A and Farm B utilise conventional pack lines. Some of the pack houses have more pack lines than others and prefer different brands regarding sorting machines, but the basic packing principles are the same.

Forklift operators load the bins on the pack line's intake, which grips the bins and tips them onto the intake conveyer belt. The citrus move through the pack line on different conveyer belts. At the start of the process, the fruit pass through the wax tunnel, which sprays them with a protective layer. This serves as protection against various infections, especially green mould. After the waxing process, the fruit pass through a sorting machine, which classifies them according to sizes. Separate belts convey the different classes to their allocated packing stations, where workers pack the citrus into boxes and stack the boxes onto pallets. Inside the pack house, workers move the pallets around using manual forklifts.

Operators move the fully stacked pallets to designated waiting areas with electric forklifts, where they stay until a truck arrives. The researcher re-probed the fruit in these waiting areas, right after the packing stage finished. Citrus that contained temperature monitoring devices could not go over the pack line, because the sorting machine classifies the fruit as unconsumable and sends them to the juice/ waste pile.

Farm A and Farm B kept six pallets aside for each consignment so that the researchers could probe the fruit without disrupting the pack house operations. The pallets stayed in the packing facility under normal conditions until trucks arrived to transport them to Company K at the Port of Cape Town. The amount of time that these pallets spent in the pack house varied between the different consignments. Forklift operators load the pallets onto the trailers with electric forklifts. Tautliners are the preferred mode of transport from Citrusdal to the Port of Cape Town, as it is a cheaper alternative to refrigerated trucks. The travel time from Citrusdal to the Port of Cape Town ranges from two and a half to three hours by truck.

4.2.4 COLD STORAGE STAGE

Upon their arrival at Company K, operators unload the pallets from the trucks with electric forklifts and stow them in cold rooms. The regulated temperature of these cold rooms ranges between 0 and 6°C (Khumalo, 2018). During the cold storage stage, Company K removes the pallets from cold storage for a brief period to inspect the fruit. Inspection occurs at ambient temperature. After inspection, the fruit re-enters cold storage and stays there until the Steri protocol commences.

4.2.5 STERI STAGE

At a time determined by Company K, operators move the pallets from cold storage to the Steri chambers with forklifts. The Steri chambers are also kept at the normal cold storage temperature of 0 to 6°C until the room is full and the Steri protocol initializes, for which the operator sets the temperature to -0.6°C. Company K utilises a double-stacking technique inside the Steri chambers, which entails stacking two pallets on top of each other. When the room is fully stowed, personnel seal the rows of pallets with plastic curtains, which ensures that the airflow between the citrus cools all the fruit efficiently. After the citrus underwent at least the full mandatory 72 hours under the Steri protocol, the researcher removed the temperature monitoring devices.

4.3 TEMPERATURE TRIALS

4.3.1 CLEMENTINES

4.3.1.1 LOAD ONE – FARM A

The researcher chose Fairchild Clementines as the cultivar for the first two temperature trials. This decision was mostly as a result of the availability of citrus and time. There is a wide range of soft citrus cultivars, harvested at different times of the year. The iButtons® captured temperature data from two consignments – one from Farm A and the other from Farm B. Degreening for these two consignments occurred at the same time, in the same chamber. After the degreening stage, the rest of the temperature profile for the second consignment is from Farm B.

The researcher probed the fruit after the drenching process, where they underwent all the processes prior to the pack line, including degreening. The first iButtons® started recording on 04/06/2018, at 17:00. The Clementines stood outside for two hours before entering the degreening room, at 19:00. Like most soft citrus cultivars, they remained in the degreening room for approximately two days. Farm A removed them from the degreening room on 06/06/2018, at 19:00. After the degreening stage, Farm A stored the fruit in the pack house to go over the pack line and kept the fruit aside under normal conditions until the researcher returned to re-probe the fruit at 10:30 on 18/06/2018 to be transported to the cold store facility. The study did not analyse the pack line segment, because the iButtons® are not compatible with the chemical processes and sorting equipment on the pack line.

The pack house/transportation stage for the first consignment lasted for approximately $10\frac{1}{2}$ hours. The citrus arrived at Company K on 18/06/2018, at 21:00, who immediately placed the fruit in the cold rooms. On 23/06/2018, at 23:00, the Steri-protocol commenced. Figures 9 and 10 indicate this when the temperatures start falling below zero degrees. The Clementines remained in the Steri chambers until Company K started loading the vessel at 15:00, on 27/06/2018. Figures 9 and 10 are time-series line graphs illustrating the abovementioned process in terms of pulp and ambient temperature. The vertical orange lines indicate when the outside/degreening stage, pack house/ transportation stage and cold storage stage end, with the last stage being the Steri-protocol stage. The circles on the graph indicate the relevant temperature breaks and temperature spikes discussed in the following sub-sections. Table 1 contains the dispersion of temperatures during each stage.

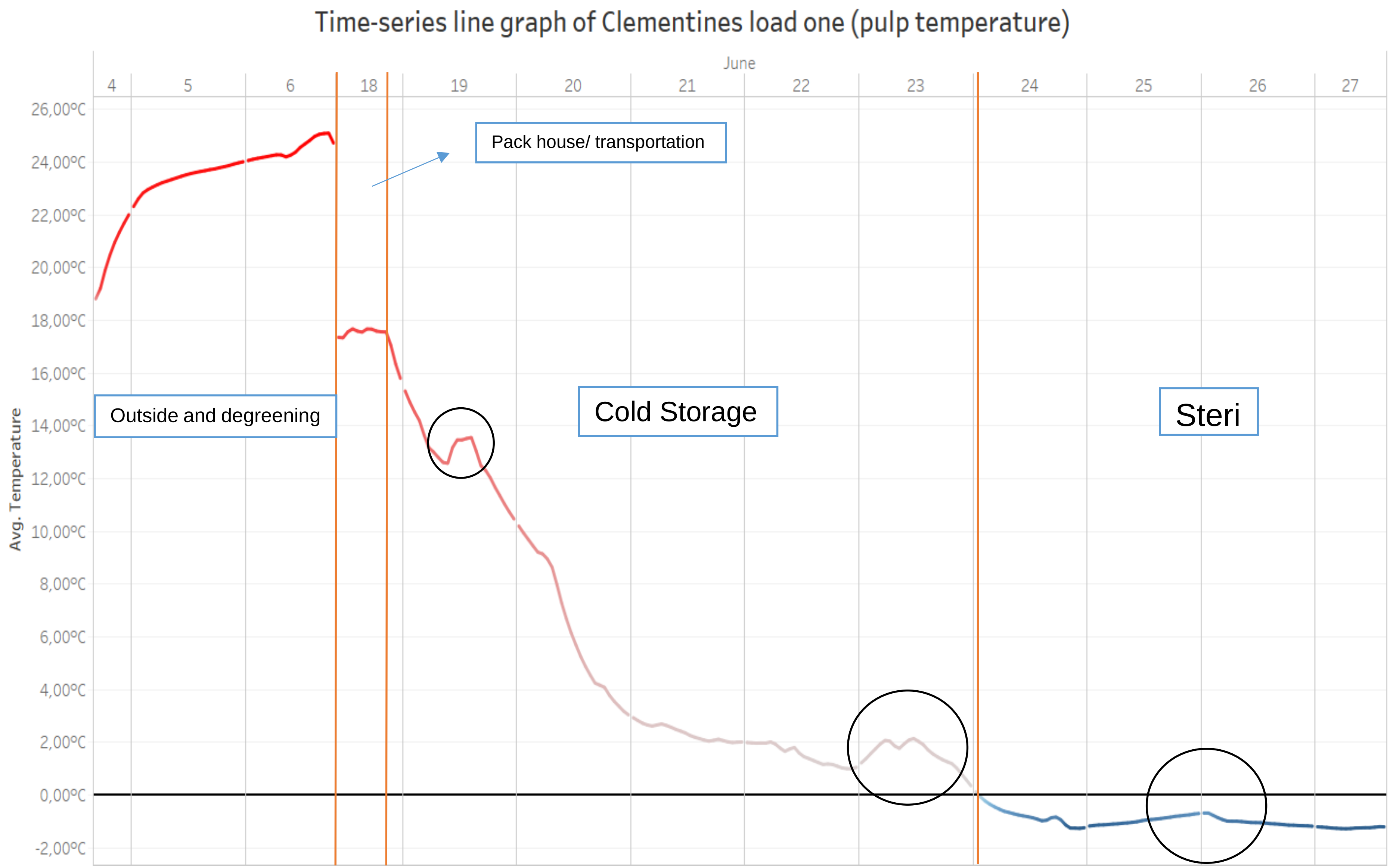

Figure 9: Time-series line graph of Clementines load one – pulp

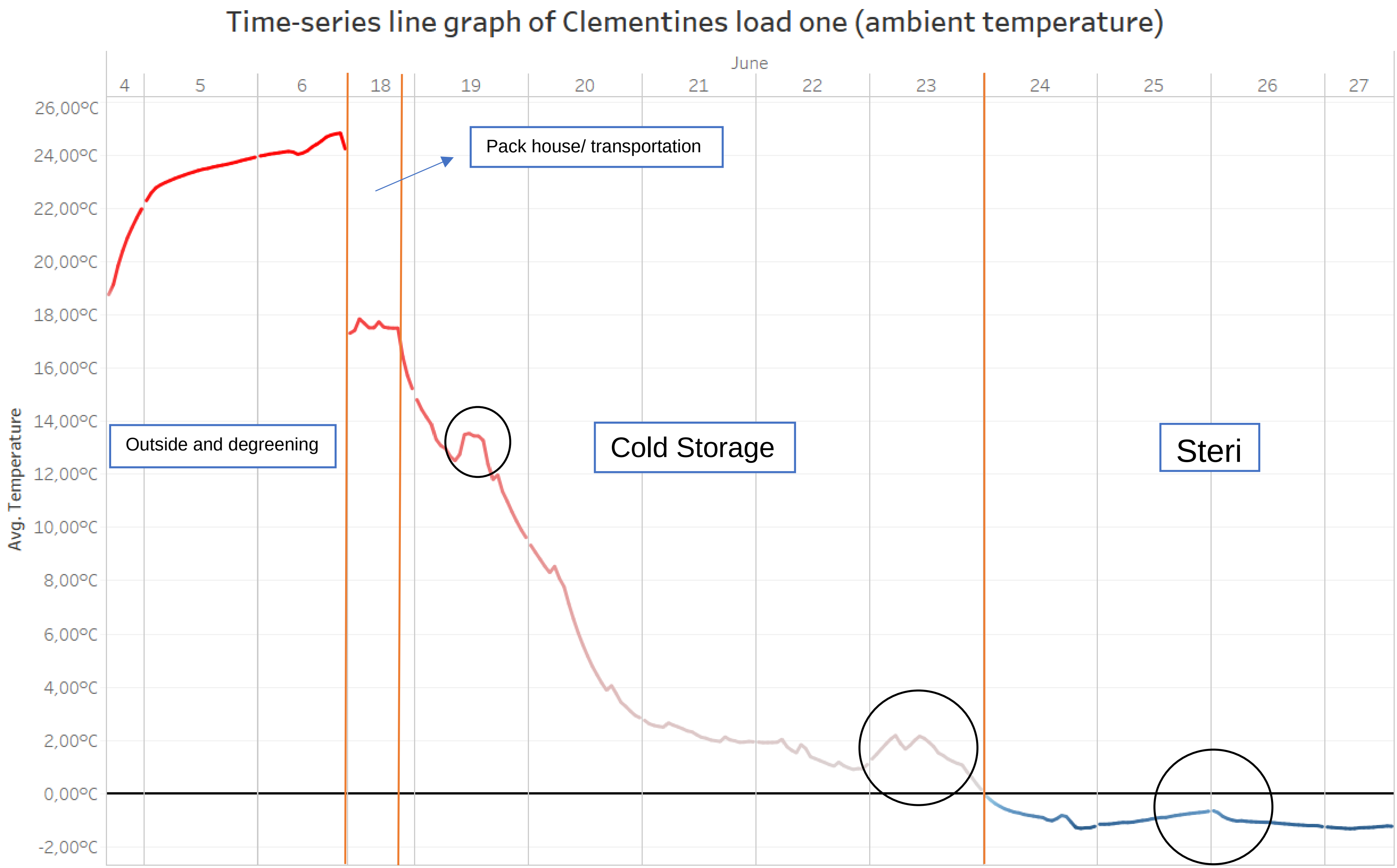

Figure 10: Time-series line graph of Clementines load one – ambient

Table 1: Temperature dispersion per stage of Clementines load one

	Outside stage		**Degreening stage**		**Pack house/ transportation stage**		**Cold storage stage**		**Steri stage**	
	Pulp	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**
Average	19.25°C	19.20°C	23.60°C	23.48°C	17.56°C	17.56°C	4.61°C	4.38°C	-1.05°C	-1.07°C
Median	18.49°C	18.82°C	23.77°C	23.79°C	17.71°C	17.71°C	2.20°C	2.20°C	-1.03°C	-1.09°C
Standard deviation (s)	1.51°C	1.59°C	1.34°C	1.35°C	0.67°C	0.79°C	5.02°C	4.90°C	0.31°C	0.30°C
Minimum	17.49°C	16.12°C	18.26°C	17.28°C	15.20°C	15.27°C	-1.44°C	-1.49°C	-1.72°C	-1.84°C
Maximum	22.59°C	23.49°C	25.73°C	25.66°C	20.13°C	20.07°C	18.61°C	18.71°C	-0.16°C	-0.25°C

4.3.1.1.1 Outside stage

The bins stood outside for two hours prior to degreening. This enabled the researcher to gain valuable insight regarding the logistical practices on Farm A and their influence on citrus' temperature profile.

The temperature remained stable for the entire two hours, showing no irregularities. This is an indication that Farm A implements proper processes that ensure high quality citrus. The standard deviations (*s*) of the pulp and ambient temperatures measured are concurrent with previous research, since ambient measurements are less influenced by fruit respiration and will, therefore, have a higher reaction rate to temperature changes. The pulp temperature showed fewer outliers and was more concentrated, as illustrated by Figure 11, which indicates higher stability.

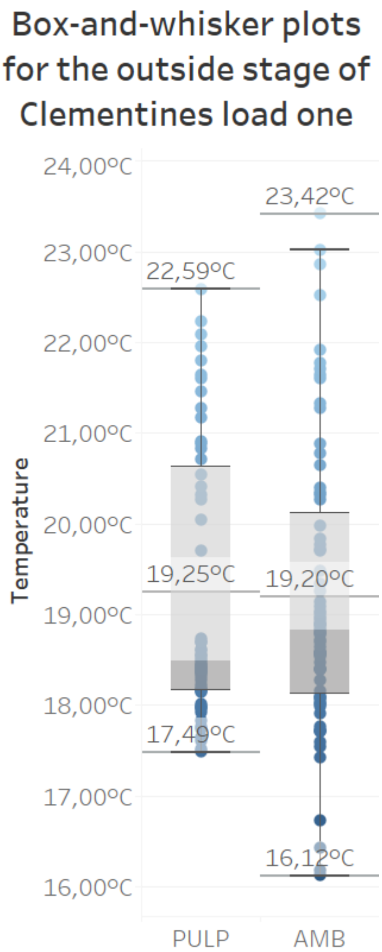

Figure 11: Box-and-whisker plot of Clementines load 1 – outside

4.3.1.1.2 Degreening stage

At 19:00, on 04/06/2018, Farm A placed the Clementines in the degreening chamber. As indicated by Figures 9 and 10, this resulted in a sudden, prominent rise in temperature. Both the pulp and ambient temperatures were stable during degreening, staying in the recommended temperature bracket of 20ºC to 25ºC, with no outliers/exceptions after the initiation of the degreening stage. The degreening room takes time to reach the pre-set temperature, hence, the minimum is below 20°C.

The average pulp temperature during degreening slightly exceeded the average ambient temperature, which is a result of the time of day and fruit respiration. The median pulp and ambient temperatures were similar at 23.77ºC and 23.79ºC respectively. Degreening started at 19:00, which is a cooler time of day. The respiratory nature of citrus generates heat energy, which decelerates the cooling process. Figure 12 is a box-and-whisker plot that illustrates the temperature dispersion for the degreening stage of Clementines load one.

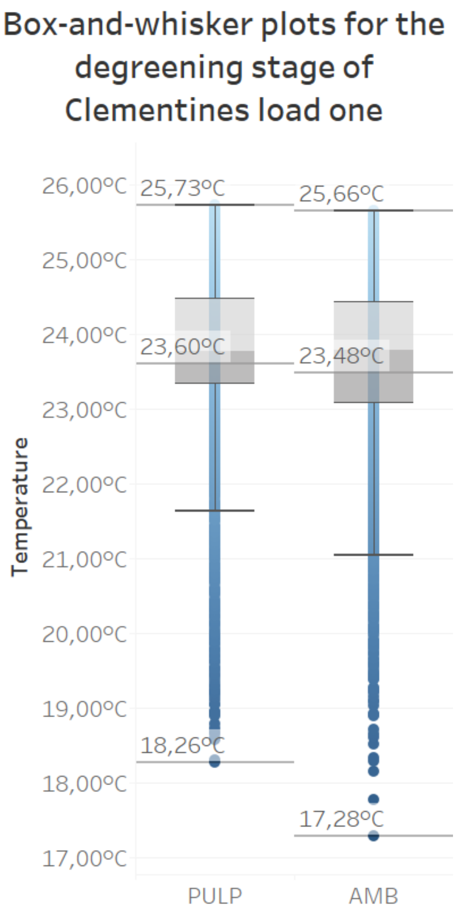

Figure 12: Box-and-whisker plot of Clementines load 1 – degreening

4.3.1.1.3 Packhouse/transportation stage

After degreening, Farm A kept the fruit aside under normal, uninterrupted pack house conditions until the researcher went back to re-probe and reactivate the iButtons® in the pack house, at 10:29 on 18/06/2018. The pulp and ambient temperatures were the most concurrent during the pack house and transportation stage, with almost identical box-and-whisker diagrams and the same average. The median pulp and ambient temperatures reflected the same tendency, both being 17.71 ºC. There were no temperature spikes/breaks during this stage. The pulp and ambient *s*-values further illustrate the consistency of the stage, being 0.67°C and 0.79°C respectively. Figure 13 illustrates the temperature dispersion for the pack house/ transportation stage of Clementines load one.

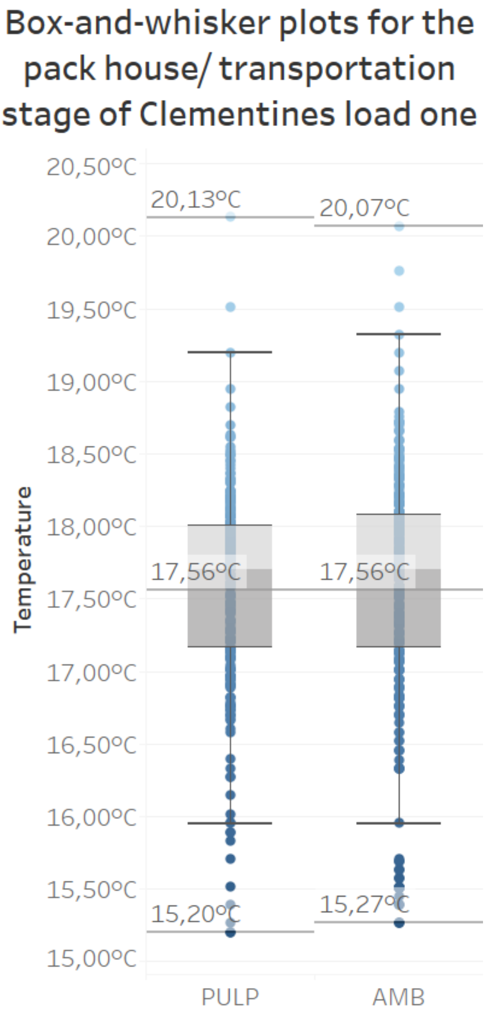

Figure 13: Box-and-whisker plot of Clementines load 1 – pack house/ transportation

Temperature spike:

At the beginning of the pack house/ transportation stage of Clementines load one, on 18/06/2018 at 11:30 all the iButtons® except PULP BOT 5 and AMB BOT 5 reflected temperature increases. None of the monitors qualified as temperature breaks. The pulp and ambient temperature dispersion during the temperature spike are highly similar. The ambient temperature is slightly more dispersed, as expected. The most probable cause of the temperature spike is an increase in day temperatures during the stage. Tautliner trailers are not ventilated and, therefore, increase according to outside temperatures.

The box-and-whisker plots for the temperature spike are not included, because the temperature increased for the entirety of the pack house/ transportation stage. Therefore, the box-and-whisker plots are identical. Table 2 illustrates the pulp and ambient temperature dispersion during the temperature spike.

Table 2: Temperature dispersion of Clementines load one – pack house/ transportation temperature spike

	Pulp	**Ambient**
Average	17.56°C	17.56°C
Median	17.71°C	17.71°C
Average increase	0.76°C	0.79°C
Median increase	0.69°C	0.75°C
Standard deviation (*s*)	0.67°C	0.79°C
Minimum	15.20°C	15.27°C
Maximum	20.13°C	20.07°C

4.3.1.1.4 Cold storage stage

For most of the temperature trials, the pallets did not enter cold storage nor Steri at the same time. This resulted in the cold storage stage being defined as follows: from when the first device enters cold storage until the last one reaches the Steri-protocol temperature. This definition influences the box-and-whisker plots' outlying values. The abovementioned definition explains why the maximum temperatures are quite high.

The minimum temperature is below the normal cold storage temperature, because some of the Clementines entered Steri before the rest. This means that the devices started recording Steri temperatures while other devices were still inside the cold rooms. A pallet's proximity to the air vents influence the time it takes for the citrus to cool down, meaning some of them cool down faster than others. The chilling injury threshold for most citrus cultivars is -1.5°C, which means that the minimum temperature in Table 1 and Figure 14 is a concern.

The pulp and ambient *s*-values were 5.02°C and 4.90°C respectively, which is an anomaly, as the ambient temperature *s* is usually higher than the pulp temperature's standard deviation. The difference, however, is insignificant. Both values are high for cold storage and indicate instability during the cold storage stage, but the time of stowage and air vent proximity of the pallets may influence these values. Figure 14 illustrates the temperature dispersion for the cold storage stage of Clementines load one.

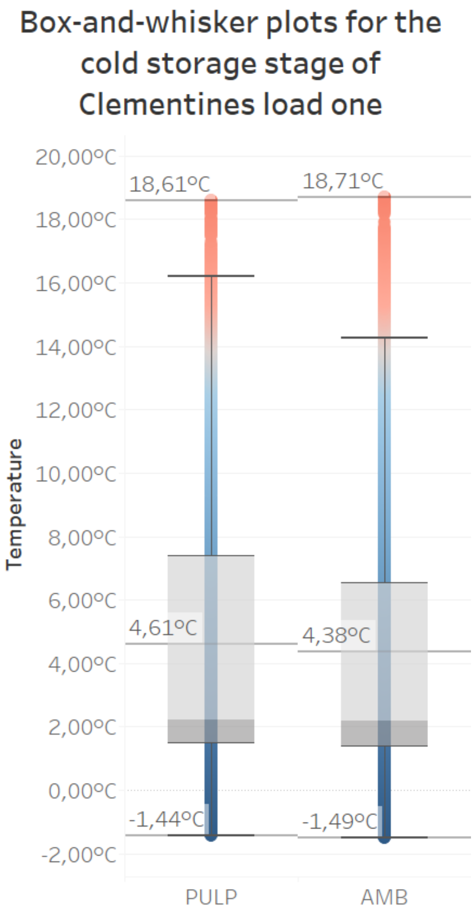

Figure 14: Box-and-whisker plot of Clementines load 1 – cold storage

Temperature breaks:

Table 3 is a summary of the temperature dispersion for the first and second temperature breaks during the cold storage stage. Only stages that experienced significant temperature spikes or temperature breaks contain these tables.

Table 3: Temperature dispersion of Clementines load one – cold storage stage first and second temperature break

	First temperature break		Second temperature break	
	Pulp	**Ambient**	**Pulp**	**Ambient**
Average	11.26°C	10.72°C	1.43°C	1.47°C
Median	8.20°C	7.24°C	1.69°C	1.51°C
Average increase	1.55°C	1.94°C	1.27°C	1.54°C
Median increase	1.47°C	2.23°C	1.29°C	1.42°C
Standard deviation (s)	2.77°C	3.08°C	0.50°C	0.59°C
Minimum	4.93°C	4.54°C	0.60°C	0.26°C
Maximum	18.30°C	18.34°C	2.66°C	3.56°C

On 19/06/2018, shortly after the pallets entered cold storage, 26 of the 32 devices recorded temperature spikes. Of these 26 devices, six increased by 2°C or more. There were confirmed temperature breaks for the following devices: PULP TOP 3, AMB MID 2 (ambient middle 2), AMB TOP 3 (ambient top 3) and AMB TOP 5. These devices showed an increase of more than 2°C for longer than 90 minutes. Figure 15 illustrates the temperature dispersion for the first temperature break during the cold storage stage of Clementines load one.

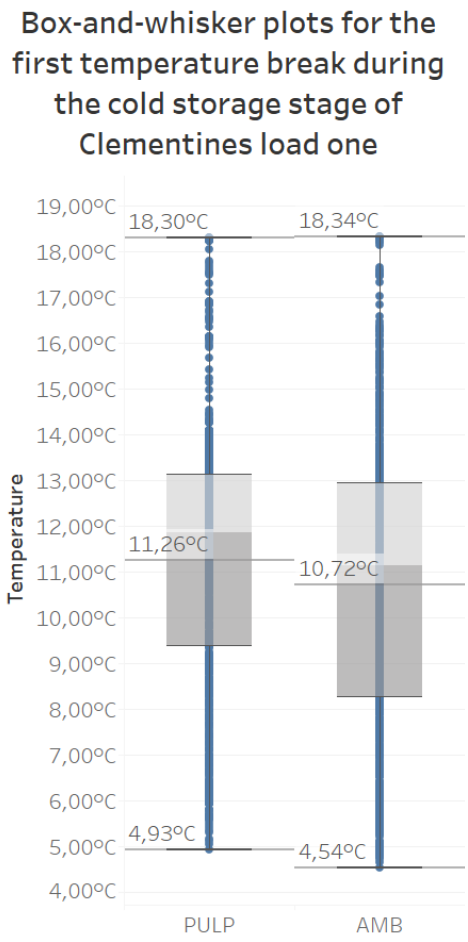

Figure 15: Box-and-whisker plot of Clementines load 1 – cold storage first temperature break

The *s*-values, being 2.77°C for the pulp temperature and 3.08°C for the ambient temperature, are larger than expected for cold storage. However, outside atmospheric temperatures influenced these values as the temperature break occurred at the beginning of the cold storage stage, meaning that some of the devices were in cold storage already, while others were still outside. AMB MID 2 recorded the highest rise at 2.7°C, while the temperature spike did not affect PULP TOP 1, PULP TOP 4, AMB MID 1, AMB MID 4, AMB TOP 1 and AMB TOP 4. Transferral between cold stores is the most probable cause of the temperature break, while another explanation may be that the personnel at Company K left the doors of the cold store open during stowage, allowing warmer outside air to enter the cold room.

On 22/06/2018, at approximately 20:30, all the devices spiked, with five of them rising by 2°C or more. All five were ambient recorders. The device that had highest increase was AMB MID 2 (ambient middle 2) at 2.82°C, while PULP BOT 6 (pulp bottom 6) was the least affected, rising by 0.44°C. The spike endured for approximately 10 hours, after which all the temperatures started decreasing. As per usual, the ambient temperatures were significantly more dispersed regarding extreme values, as Figure 16 illustrates. Although all the devices experienced temperature spikes, only one device, AMB MID 2, met both definitions of a temperature break. The temperature of this device increased by 2.82°C and stayed above the 2°C threshold for longer than 90 minutes. Figure 16 illustrates the temperature dispersion for the second temperature break during the cold storage stage of Clementines load one.

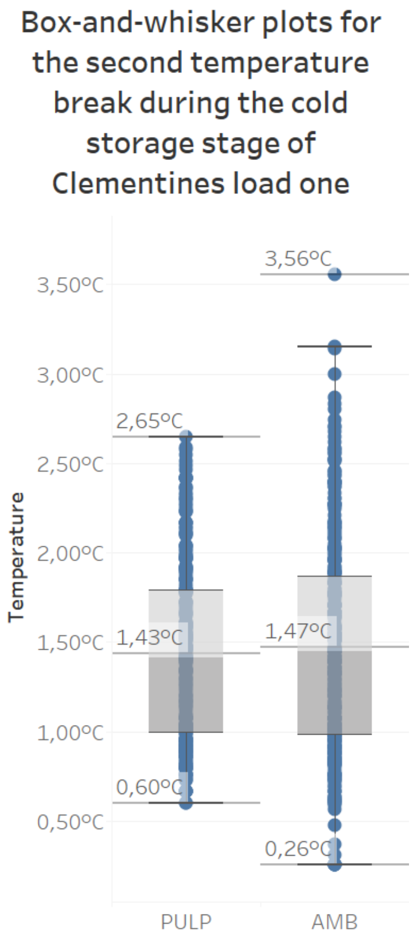

Figure 16: Box-and-whisker plot of Clementines load 1 – cold storage second temperature break

Three of the four consignments from this study followed the same trend as load one, spiking shortly before the Steri stage. This is a concerning occurrence and may be an indication of inefficiencies during the switch-over from the cold rooms to the Steri chambers. The most probable cause of the break is that Company K left the pallets outside for too long while moving them from the cold rooms to Steri chambers and did not keep the Steri chambers at a constant temperature during stowage.

4.3.1.1.5 Steri stage

The Steri stage is defined as follows: from when the last device reaches -0.6°C until the first device exits from the chambers. Both pulp and ambient averages fall below the prescribed Steri-protocol temperature of -0.6°C, which is not a concern, as the chilling injury threshold is -1.5°C. The case is the same for the pulp and ambient median temperatures of -1.03ºC and -1.09ºC.

The maximum pulp temperature is considerably higher than the required -0.6°C, but the chamber would normally still pass inspection. If the temperature exceeded 0°C, Company K would have been obliged force-cool the citrus again to below 0°C for another 24 hours. The minimum pulp temperature is alarming, as it exceeds the chilling injury threshold of -1.5°C. Figure 17 illustrates the temperature dispersion for the Steri stage of Clementines load one.

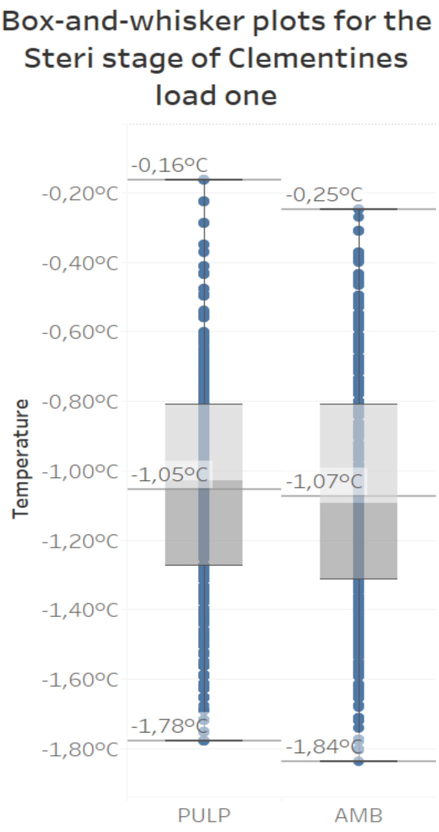

Figure 17: Box-and-whisker plot of Clementines load 1 – Steri

Temperature Spike:

There was a prolonged temperature spike during the middle of the Steri stage, but the temperature never went above 0°C. After decreasing to a minimum, the temperature for all pulp and ambient devices increased gradually and reached a maximum of -0.16°C, before decreasing again. The spike endured for approximately one day, taking place between 25/06/2018 and 26/06/2018. Table 4 summarizes the spread of the temperatures during this temperature spike.

Table 4: Temperature dispersion of Clementines load one – Steri temperature spike

	Pulp	**Ambient**
Average	-0.97°C	-0.97°C
Median	0.73°C	0.75°C
Average increase	0.62°C	0.74°C
Median increase	0.60°C	0.72°C
Standard deviation (*s*)	0.29°C	0.31°C
Minimum	-1.69°C	-1.8°C
Maximum	-0.16°C	-0.25°C

Operational inefficiencies are the most probable cause of the temperature spikes, because personnel are not allowed to open the chambers while Steri is underway. This means that hot air could not enter the chamber (except in the case of a break-down). Therefore, most probably, management at Company K noticed that the temperature was nearing the chilling injury threshold and took preventative measures by increasing the pre-set temperature. Consequently, the temperature inside the chamber increased too quickly and some of the fruit nearly breached the 0°C threshold. Figure 18 illustrates the temperature dispersion during the temperature spike.

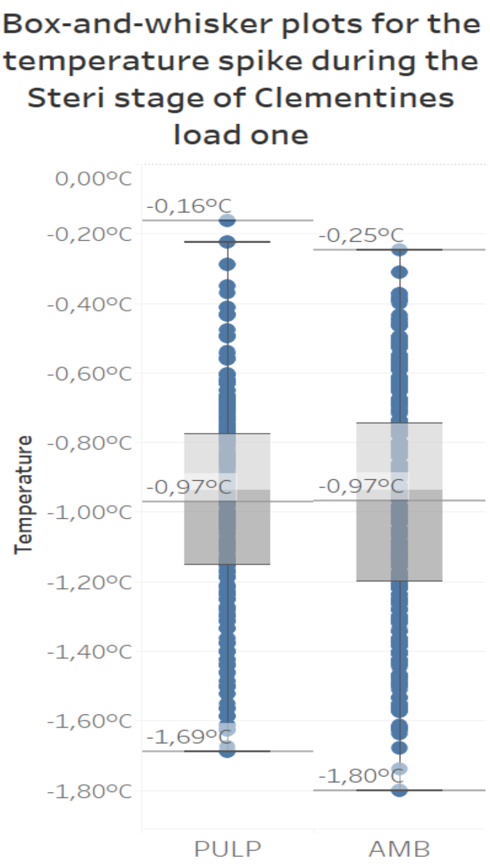

Figure 18: Box-and-whisker plot of Clementines load 1 – Steri temperature spike

4.3.1.1.6 Conclusion

<u>Outside stage:</u>

The temperature was stable while the Clementines stood outside, which indicates logistical practices that are efficient and reliable. The pulp temperature was less volatile than the ambient temperature, as a result of fruit respiration.

<u>Degreening stage:</u>

The *s*-values during the degreening stage indicate stable temperatures. The bins entered the chamber at a later stage of the day, causing the average pulp temperature to be slightly higher than the average ambient temperature. The ambient devices reacted to the temperature decrease quicker than the pulp devices.

<u>Pack house/ transportation stage:</u>

The iButtons® reflected the most concurrent pulp and ambient temperatures during this stage. At the beginning of the stage the temperature started increasing for its entire duration. Only two devices did not reflect temperature increases. None of the devices qualified as temperature breaks. The most probable cause of the temperature spike is an increase of outside temperatures as a result of the time of day.

Cold storage stage:

Not all the pallets entered cold storage at the same time, which may cause the data to look more dispersed than it is, especially concerning extreme values. The minimum temperature is a concern as it borders the chilling injury threshold. Four temperature monitoring devices picked up a temperature break during the first break period, three were ambient recorders and one was a pulp recorder. Pallet transferral or inefficient stowage processes are the most probable cause of the temperature breaks. The second temperature break occurred shortly before the Steri stage, only AMB MID 2 qualified as a temperature break. During the switch-over from the cold store to the Steri chamber, the pallets stood outside for too long, leading to the temperature break.

Steri stage:

The average and median temperature was considerably lower than -0.6°C, but chilling injury was not yet a risk at this point. The maximum temperature went close to the 0°C threshold, where the room would not have passed inspection. The minimum temperature of -1.72°C is concerning, as chilling injury becomes a risk at -1.5°C. Overall, the temperature was stable during Steri with low *s*-values. The Steri stage also experienced a temperature spike, but the temperature never went above 0°C. The spike may have been a result of operational inefficiencies. When the Steri chamber operators realised the chamber was too cold, they most likely tried to fix the problem and over-compensated.

4.3.1.2 LOAD TWO – FARM B

The researcher probed the second consignment of Fairchild Clementines at Farm B. As mentioned previously, the degreening of these Clementines occurred alongside those of the first consignment, at Farm A. Therefore, like load one, the first devices for load two started measuring the citrus' temperature on 04/06/2018, at 17:00. After recording the entire outside and degreening stages, a manager at the pack house of Farm A removed the devices from the fruit at 19:00 on 06/06/2018 and kept them aside in an office. The devices remained there until Farm B confirmed a packing date.

The numbers concerning dispersion for the second load of Clementines are very similar to those of the first one, because the fruit were together for these two stages. Therefore, the same forces that impacted load one also impacted load two and vice versa. As a result, the first two sub-sections (outside stage and degreening stage) for this consignment are shorter than for the rest of the paper.

On 19/06/2018, the researcher returned to Farm A to collect the devices and headed to Farm B to probe the second consignment for its pack house/ transportation stage. The first iButtons®

activated on 19/06/2018, at 09:30. The pack house/ transportation stage lasted for five hours and the citrus entered the cold storage at Company K at 14:30 on the same day. At 12:30 on 25/06/2018 the first iButtons® began reflecting negative values, which means that Company K initialized the Steri Protocol. On 27/06/2018 at 15:00 the researcher removed the devices from the Steri chambers.

Figures 19 and 20 are time-series line graphs illustrating the temperature profile of Clementines load two. The vertical orange lines indicate when the outside/degreening stage, pack house/ transportation stage and cold storage stage end, with the last stage being the Steri-protocol stage. The circles on the graph indicate the relevant temperature breaks and temperature spikes, discussed in the following sub-sections. Table 5 contains the dispersion of temperatures during each stage.

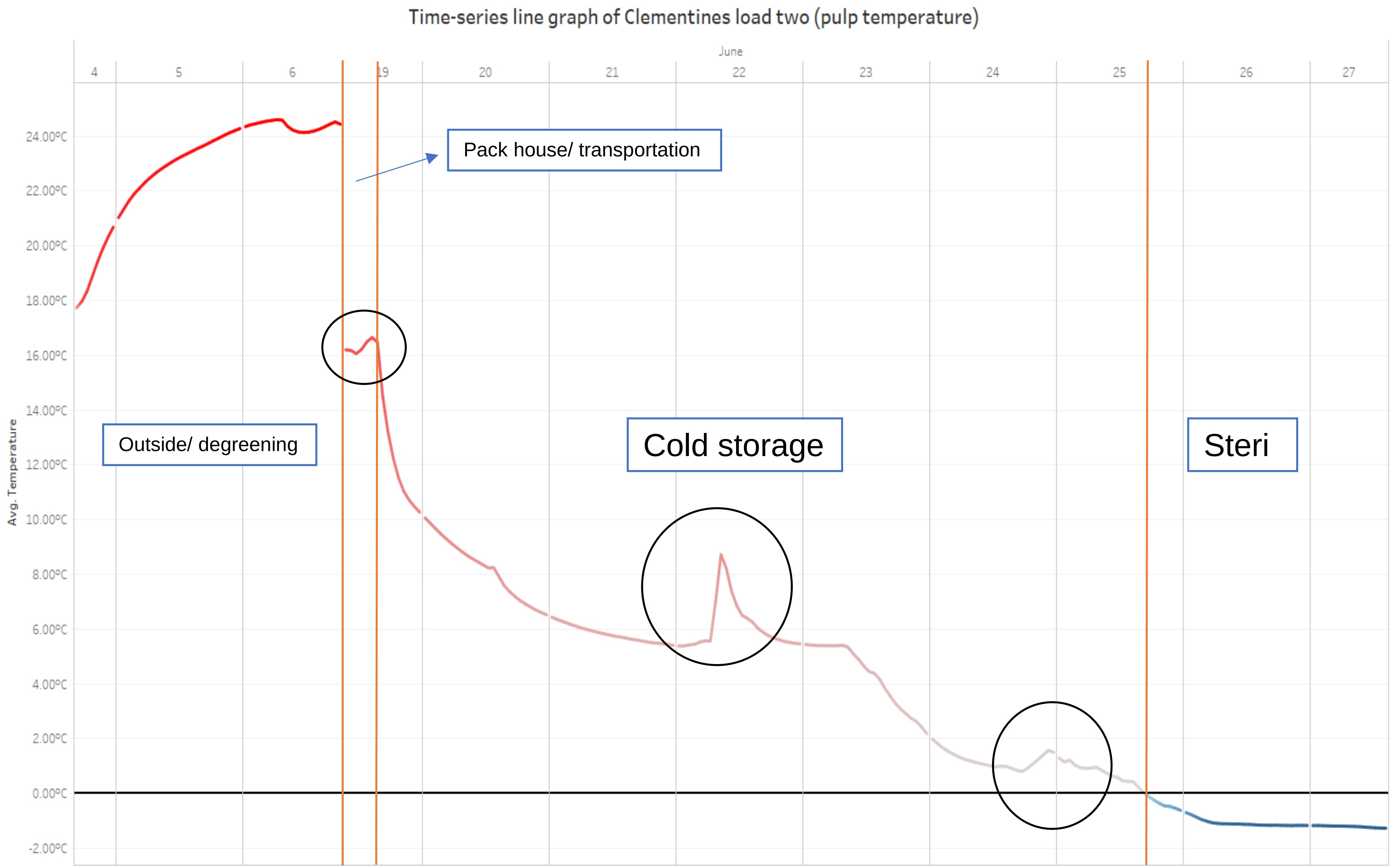

Figure 19: Time-series line graph of Clementines load two – pulp

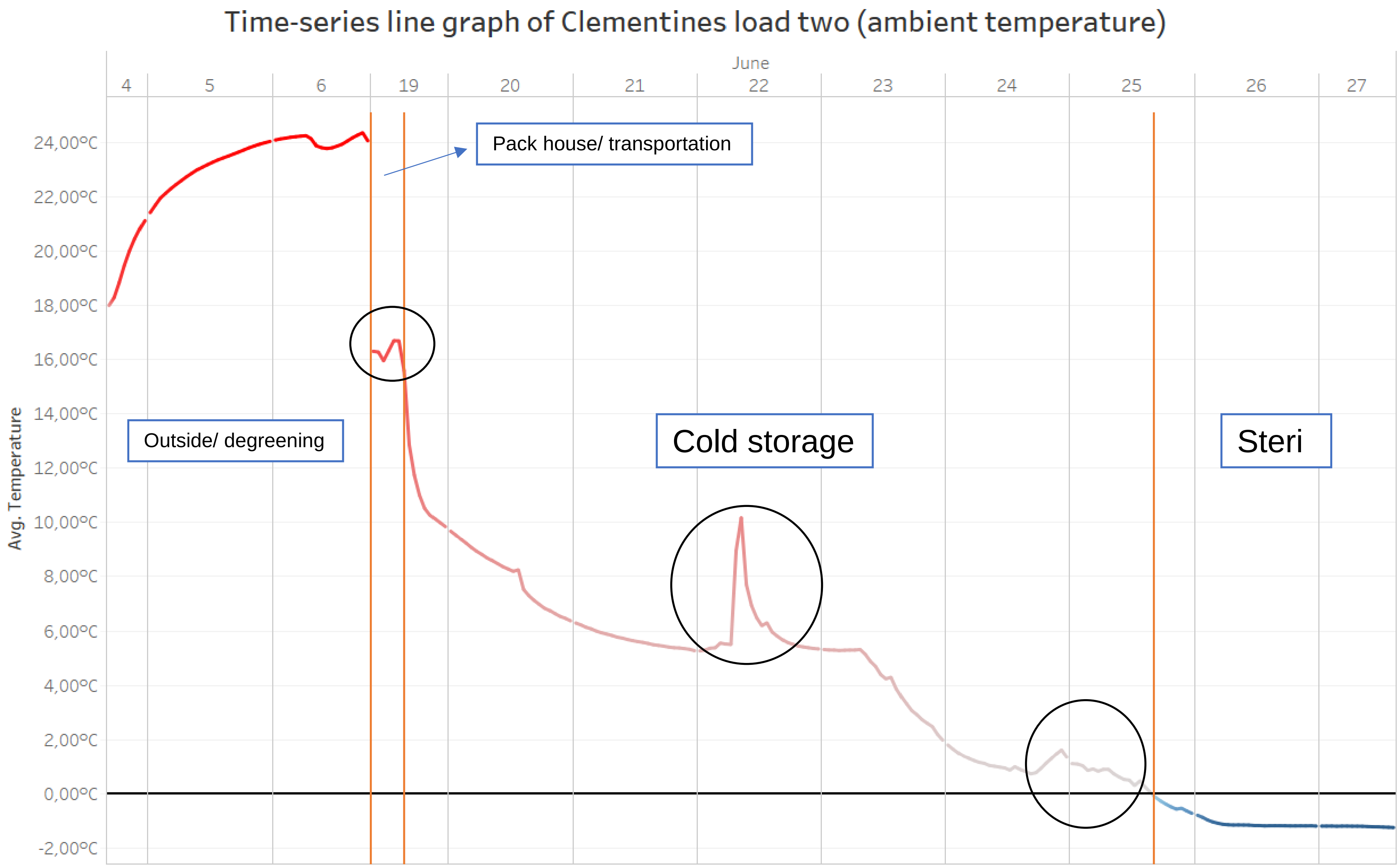

Figure 20: Time-series line graph of Clementines load two – ambient

Table 5: Temperature dispersion per stage of Clementines load two

	Outside stage		Degreening stage		Pack house/ transportation stage		Cold storage stage		Steri stage	
	Pulp	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**
Average	17.97°C	18.31°C	23.182°C	23.131°C	16.26°C	16.33°C	4.67°C	4.51°C	-1.17°C	-1.18
Median	17.94°C	18.22°C	23.56°C	23.57°C	16.11°C	16.22°C	4.32°C	4.20°C	-1.18°C	-1.25°C
Standard deviation (s)	0.27°C	0.55°C	1.75°C	1.49°C	1.55°C	1.68°C	4.06°C	3.99°C	0.24°C	0.19°C
Minimum	17.52°C	17.53°C	17.91°C	17.97°C	13.25°C	13.45°C	-1.26°C	-1.39°C	-2.29°C	-1.49°C
Maximum	18.68°C	20.87°C	25.75°C	25.76°C	20.16°C	22.53°C	20.52°C	22.32°C	-0.49°C	-0.6°C

4.3.1.2.1 Outside stage

Like load one, the temperature remained stable for the entire two hours that the citrus spent outside. This consignment had a significantly lower *s*-value than the first one. The most probable cause is sunlight exposure, because the researcher allocated the bins in this consignment near to each other during the outside stage. This could mean that the fruit from load one experienced a brief period of sunlight exposure, which the fruit from load two did not. The lower average-, median- and maximum temperatures during the outside stage of load two further strengthens this theory. These differences, however, are insignificant and do not influence fruit quality. The box-and-whisker plots in Figure 21 illustrates the temperature dispersion of Clementines load two during this stage.

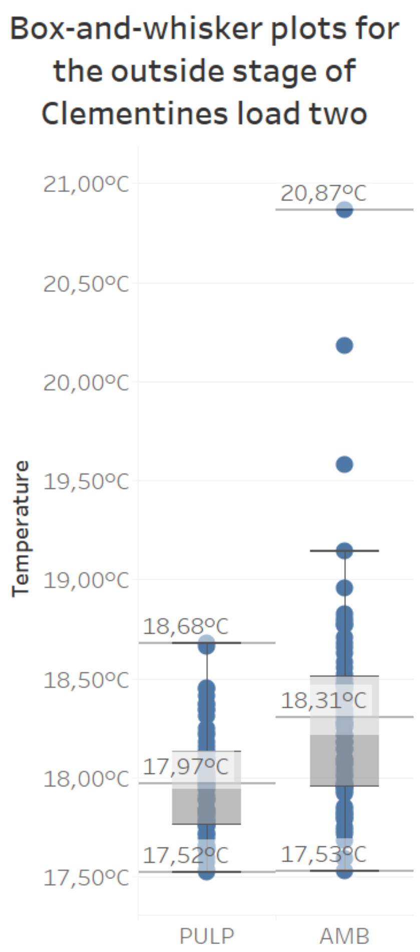

Figure 21: Box-and-whisker plots of Clementines load two – outside

The diagram's ambient side shows three values that are significantly higher than the rest of the ambient and pulp readings. This may also strengthen the theory that there was a brief period of sunlight exposure to some of the citrus, but that it was not long to enough influence the pulp temperature significantly.

4.3.1.2.2 Degreening stage

Farm A placed the citrus in the degreening chamber at 19:00, on 04/06/2018. Like the first consignment, the degreening stage produced stable temperatures. The measures of dispersion look almost identical to load one, with no significant differences. The *s*-values differ slightly, but the difference is insignificant. Figure 22 illustrates the temperature dispersion for the degreening stage.

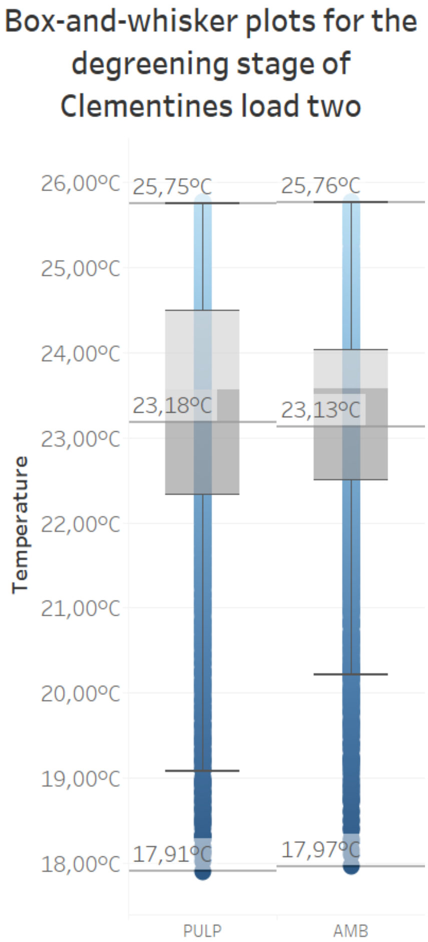

Figure 22: Box-and-whisker plots of Clementines load two – degreening

4.3.1.2.3 Pack house/ transportation stage

The researcher probed the second consignment a day after the first consignment at the pack house of Farm B. Farm B kept the fruit aside under normal, uninterrupted pack house conditions until the researcher probed them. The devices started recording at 09:30 on 19/06/2018. The probed citrus stood in a designated waiting area until a truck arrived to transport them to Company K. During this waiting period the temperature was stable, showing no irregularities. When the truck departed for Company K, the temperature of all the devices gradually started increasing until the end of the trip. Figure 23 illustrates the temperature dispersion for the degreening stage.

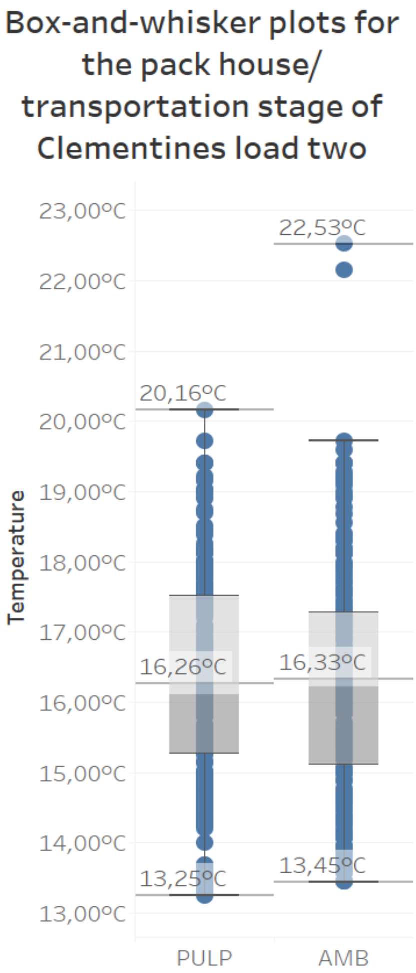

Figure 23: Box-and-whisker plots of Clementines load two – pack house/ transportation

Temperature break:

Three of the ambient temperature recorders indicated temperature breaks, namely AMB BOT 2, AMB BOT 4 and AMB MID 4. There were no pulp temperature breaks. Table 6 and Figure 23 show that the ambient temperatures were higher during the temperature break, with a higher average, median, minimum and maximum. The average ambient temperature increase during the temperature break was significantly higher than the average pulp temperature increase, as is the case for the median.

This indicates that the temperature increased for a short period, which is why ambient devices recorded all the temperature breaks. The temperature did not increase for long enough to cause a temperature break in the pulp devices. The pulp and ambient *s*-values further explain the short duration of the break, as the ambient *s* is significantly higher than the pulp *s*.

The most probable cause of the temperature break is that the atmospheric temperature increased as the time of day progressed, which caused the temperature inside the tautliner trailer to increase accordingly, because the temperature inside tautliner trailers is not regulated. Table 6 illustrates the temperature dispersion during the temperature break. The section does not include a box-and-whisker diagram for the temperature break, because the break occurred during the entire stage. Therefore, the box-and-whisker plot is the same as Figure 23.

Table 6: Temperature dispersion of Clementines load two – pack house and transportation temperature break

	Pulp	**Ambient**
Average	16.26°C	16.33°C
Median	16.12°C	16.22°C
Average increase	1.16°C	1.94°C
Median increase	1.19°C	1.81°C
Standard deviation (*s*)	1.54°C	1.68°C
Minimum	13.25°C	13.45°C
Maximum	20.16°C	22.53°C

4.3.1.2.4 Cold storage stage

As Section 4.3.1.1.4 explains, the cold storage stage reflects a high maximum temperature because all the citrus did not enter the cold room at the same time. Section 4.3.1.1.4 also explains that the pallets were not moved to the Steri chambers simultaneously, hence the minimum temperature is lower than the average cold storage temperature. Figure 24 illustrates that the pulp and ambient temperatures during the cold storage stage were similar. The ambient temperature was marginally more dispersed. The box-and-whisker plots in Figure 24 show the pulp and ambient temperature dispersion during the cold storage stage.

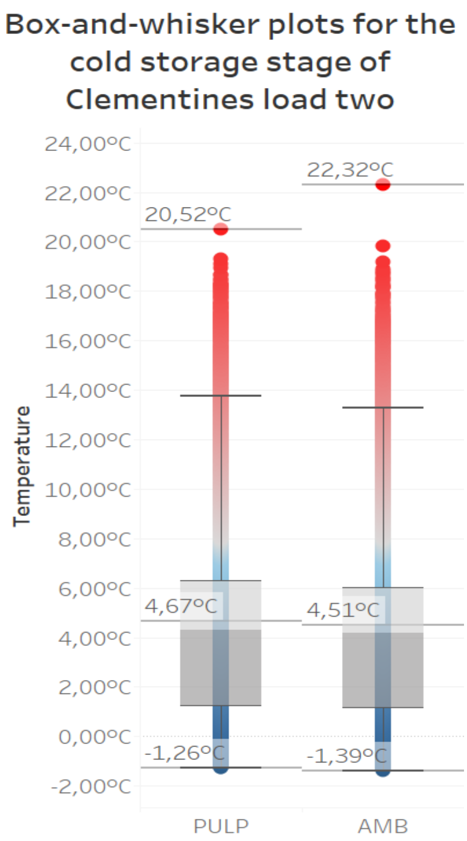

Figure 24: Box-and-whisker plots for Clementines load two – cold storage

Temperature break and temperature spike:

During the cold storage stage there were two periods where the temperature increased significantly. Table 7 illustrates the pulp and ambient temperature dispersion for the periods that the temperature increased during the cold storage stage. The columns under "temperature break" correspond to the first period and those under "temperature spike" to the second period.

Table 7: Temperature dispersion of Clementines load two – cold storage temperature break and temperature spike

	Temperature break		**Temperature spike**	
	Pulp	**Ambient**	**Pulp**	**Ambient**
Average	6.12°C	6.13°C	6.12°C	6.13°C
Median	5.37°C	6.24°C	1.07°C	1.07°C
Average increase	3.83°C	5.55°C	0.65°C	0.94°C
Median increase	3.32°C	5.27°C	0.72°C	0.94°C
Standard deviation (*s*)	2.36°C	2.40°C	0.32°C	0.36°C
Minimum	3.66°C	3.79°C	3.66°C	3.79°C
Maximum	13.26°C	14.04°C	13.26°C	14.04°C

Figure 19 and Figure 20 indicate a sharp temperature increase on 22/06/2018. This increase marks the first of the two temperature increases during the cold storage stage. The study revealed several severe temperature breaks during this period. The consignment contained 33 iButtons® in total, of which 27 indicated temperature breaks during the first period. Thirteen pulp monitoring devices experienced temperature breaks, while the other 14 devices were ambient monitors. PULP TOP 2 recorded the most severe rise of the pulp monitors, which was 7.52°C. AMB TOP 2 recorded the most severe rise of the ambient monitors, which was 10.05°C. These two devices were in the same box, which indicates that this box received the highest amount of heat exposure during the temperature break.

The most probable cause of the temperature break is that the fruit remained out of cold storage for too long during inspection. That specific day was a warm and sunny day with 0% precipitation, which could have added to the severity of the temperature breaks. Figure 25 illustrates the temperature dispersion of the pulp and ambient temperature during the temperature break.

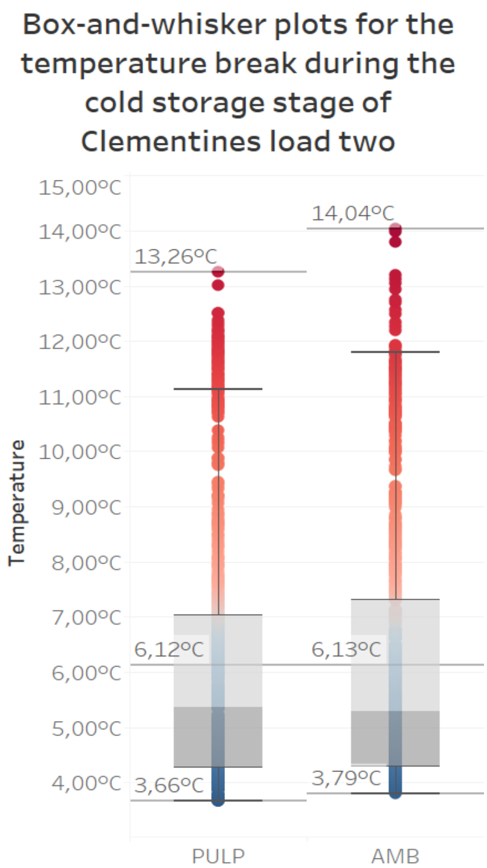

Figure 25: Box-and-whisker plots of Clementines load two – cold storage temperature break

At the end of the day on 24/06/2018, Figure 19 and Figure 20 indicate another prominent temperature increase. This increase was not as severe as the first one, as the *s*-values in Table 7 indicate. PULP MID 1 experienced the highest pulp temperature increase during the temperature spike, at 1.26°C. AMB TOP 3 had the highest ambient temperature increase. As a result, none of the temperature increases qualified as temperature breaks.

As mentioned in section 4.3.1.1.4, temperature spikes / temperature breaks during this part of the cold storage stage are a common occurrence, because Company K moves the pallets from cold storage to Steri chambers and exposes the fruit to atmospheric temperatures. Figure 26 illustrates the pulp and ambient temperature dispersion during the temperature spike. As expected, the ambient temperature was slightly more dispersed than the pulp temperature.

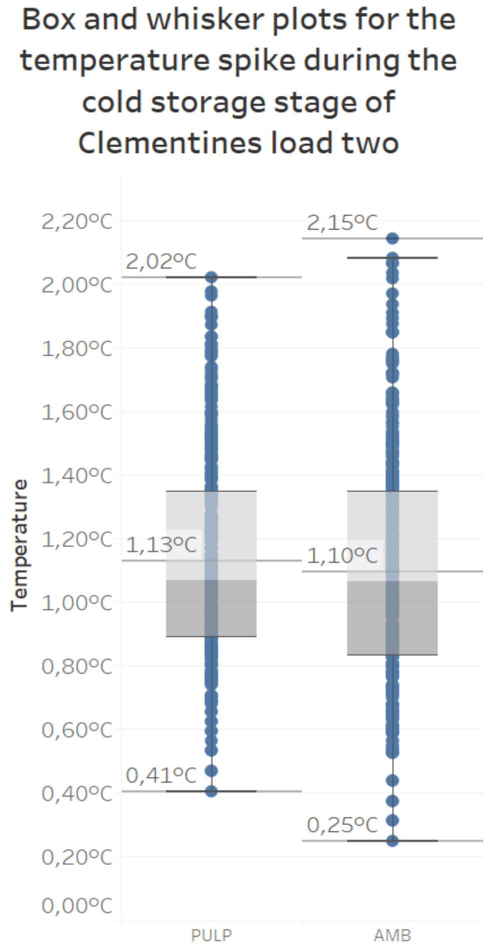

Figure 26: Box-and-whisker plots of Clementines load two – cold storage temperature spike

4.3.1.2.5 Steri stage

As Figure 19 and Figure 20 illustrate, the temperature was stable in terms of increases and volatility, as the figures do not contain any spikes. However, the box-and-whisker plots (Figure 27) contain outlying values that are concerning. The maximum pulp temperature is slightly above the prescribed Steri temperature of -0.6°C, but it is not a concern and likely resulted from fruit respiration. The pulp and ambient averages are almost identical and fall well below the Steri protocol temperature, which is a positive sign. The median pulp and ambient temperatures are also similar at -1.18ºC and -1.25ºC

The temperature dispersion for the Steri stage of this consignment is an anomaly, because the pulp temperatures are significantly more dispersed than the ambient temperatures. Usually, it is the other way around. The difference, however, is insignificant. Furthermore, one device dropped below -1.50°C, the CI threshold.

The minimum pulp temperature recorded was -1.56°C, which is below the CI threshold and may influence the quality negatively. The most probable cause for these low temperatures are the specific device's proximity to the air vent. The pulp temperatures were not only more dispersed in terms of the bottom whiskers, but also in terms of the top whiskers, which is normal and a result of respiration. Figure 27 illustrates the temperature dispersion during the Steri stage.

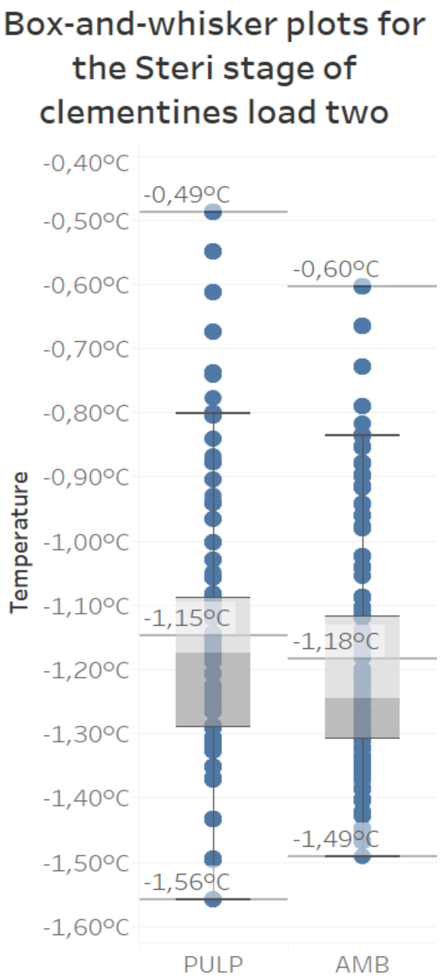

Figure 27: Box-and-whisker plots of Clementines load two – Steri

4.3.1.2.6 Conclusion

Outside stage:

Like Clementines load one, the temperature was stable during the outside stage. The researcher suspects that there was a brief period of sunlight exposure during the outside stage of the first two consignments, as load one reflects a higher *s*-value and the ambient box-and-whisker plot for load two contains three outliers.

Degreening stage:

The degreening stage temperatures were the most stable for this consignment and reflected no irregularities. The *s*-values differ slightly to those of Load two, but the differences are insignificant.

Pack house/ transportation stage:

The study identified the first temperature break for Clementines load two during this stage. The temperature started rising when the truck departed from Farm B in the morning. All three of the reported temperature breaks were ambient recorders, which means that the break did not last long enough to influence the pulp temperature. The most probable cause of the temperature break is the increase of atmospheric temperature as the day progressed, which caused the temperature inside the tautliner trailer to rise accordingly.

Cold storage stage:

There were two temperature increase periods during the cold storage stage. During the first period, several severe pulp and ambient temperature breaks occurred with some of the pulp iButtons® increasing by more than 7°C. A break of this stature may have debilitating effects on citrus' quality. The most probable cause of the temperature break is that the fruit remained outside of cold storage for too long during inspection, which occurs at ambient temperature.

The second period reflected several temperature spikes during the switch-over from cold storage to Steri, but none of them qualified as temperature breaks. This trend was evident across all the consignments that the study analysed. During the switchover, a period of exposure to atmospheric temperatures cause a sudden spike in temperatures.

Steri stage:

The time-series line graphs (Figure 19 and Figure 20) reflect that the temperature was stable during the Steri stage. There are, however, several outliers on the pulp temperature box-and-whisker plot that are a concern, as they drop well below the CI threshold. The most probable cause is the device's proximity to an air vent.

4.3.2 NAVELS

4.3.2.1 LOAD ONE – FARM A

The researcher conducted a second round of temperature trials, this time on Navel oranges. Both consignments came from Farm A, who degreened the two consignments (twelve bins) together.

During the first attempt at mapping the cold chain of load one from the pack house/ transportation stage and onwards, the researcher programmed the iButtons® to activate at 10:00, but the truck departed before that time. Therefore, the first attempt was unsuccessful, because it missed a part of the cold chain. Using the same data for the outside and degreening stages, the researcher re-attempted the trial, this time successfully mapping the entire journey.

The iButtons® activated on 12/06/2018, at 17:00 to measure the outside stage of Navels load one. The citrus stood outside for a significantly longer period than the Clementines, which enabled the researcher to gather a substantial amount of valuable data regarding Farm A's logistical practices. The outside stage was 20 hours long, meaning the fruit stood outside on the packing premises for almost an entire day.

The degreening stage started at 13:00 on 13/06/2018. The degreening process for oranges is usually a day longer than for soft citrus, because oranges have different characteristics. On 16/06/2018, at 13:00, Farm A removed the citrus from the degreening chamber. A representative from the farm removed the iButtons® from the fruit and kept them in their office until Farm A could confirm a suitable packing date. Farm A kept the fruit aside under normal, uninterrupted pack house conditions until the researcher returned.

The researcher returned on 07/08/2018 to re-do the first trial, because the first attempt was unsuccessful. The iButtons® activated on 07/08/2018 at 10:30 to record the pack house/ transportation stage. This time, they captured the entire cold chain. The pack house/ transportation stage lasted for ten hours.

At 20:30 on 07/08/2018 the fruit arrived at Company K, who placed the pallets into cold storage. The citrus remained in cold storage for approximately seven days, which is longer than usual. This is often as a result of delays in the shipping schedule. On 14/08/2018 at 23:30, Company K moved the pallets from cold storage to the Steri chambers. On 17/08/2018 at 10:00, the researcher removed the probed citrus from the Steri chambers.

Figures 28 and 29 are time-series line graphs illustrating the temperature profile of Clementines load two. The vertical orange lines indicate when the outside/degreening stage, pack house/ transportation stage and cold storage stage end, with the last stage being the Steri-protocol stage. The circles on the graph indicate the relevant temperature breaks and temperature spikes, discussed in the following sub-sections. Table 8 contains the dispersion of temperatures during each stage.

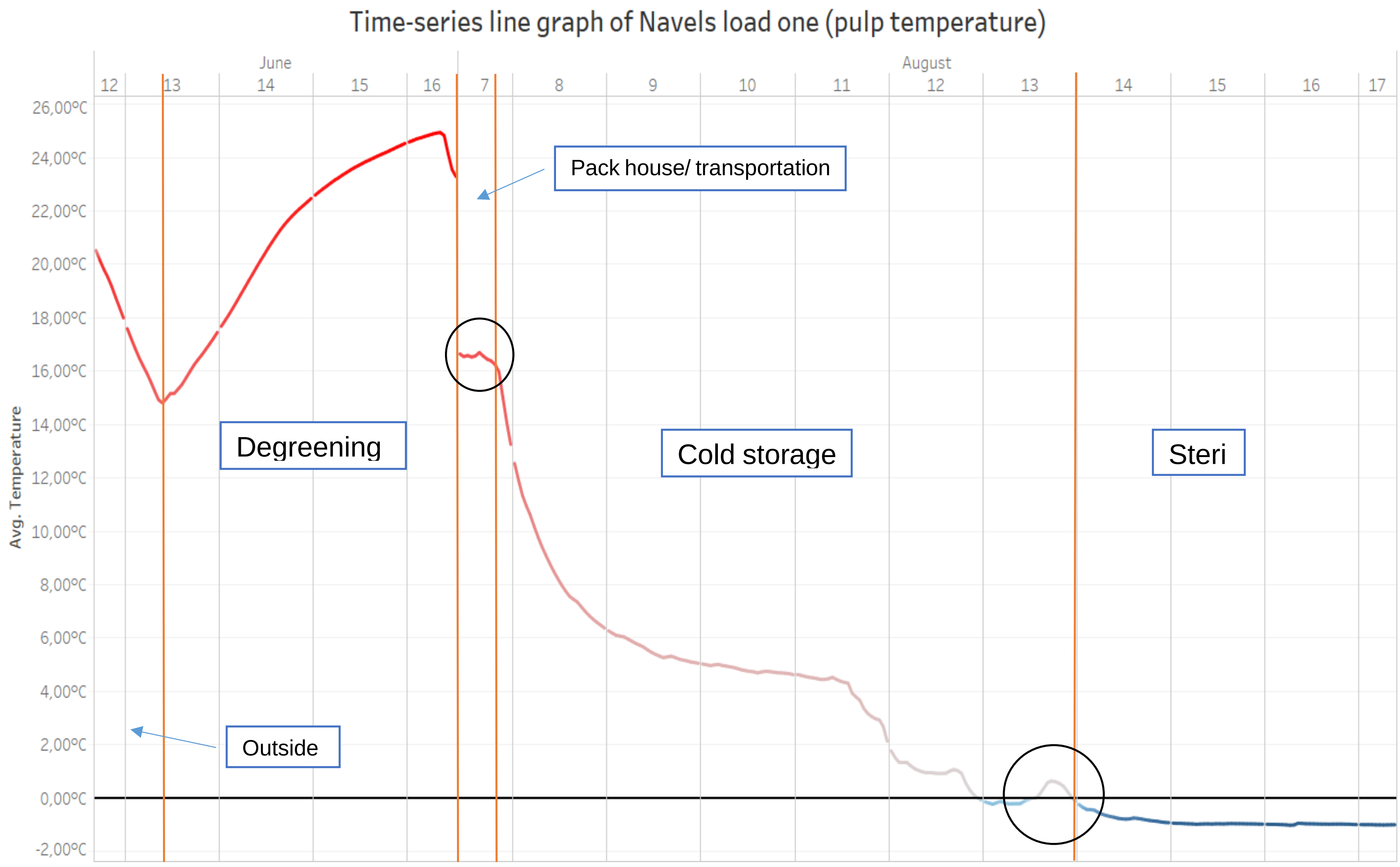

Figure 28: Time-series line graph of Navels load one – pulp

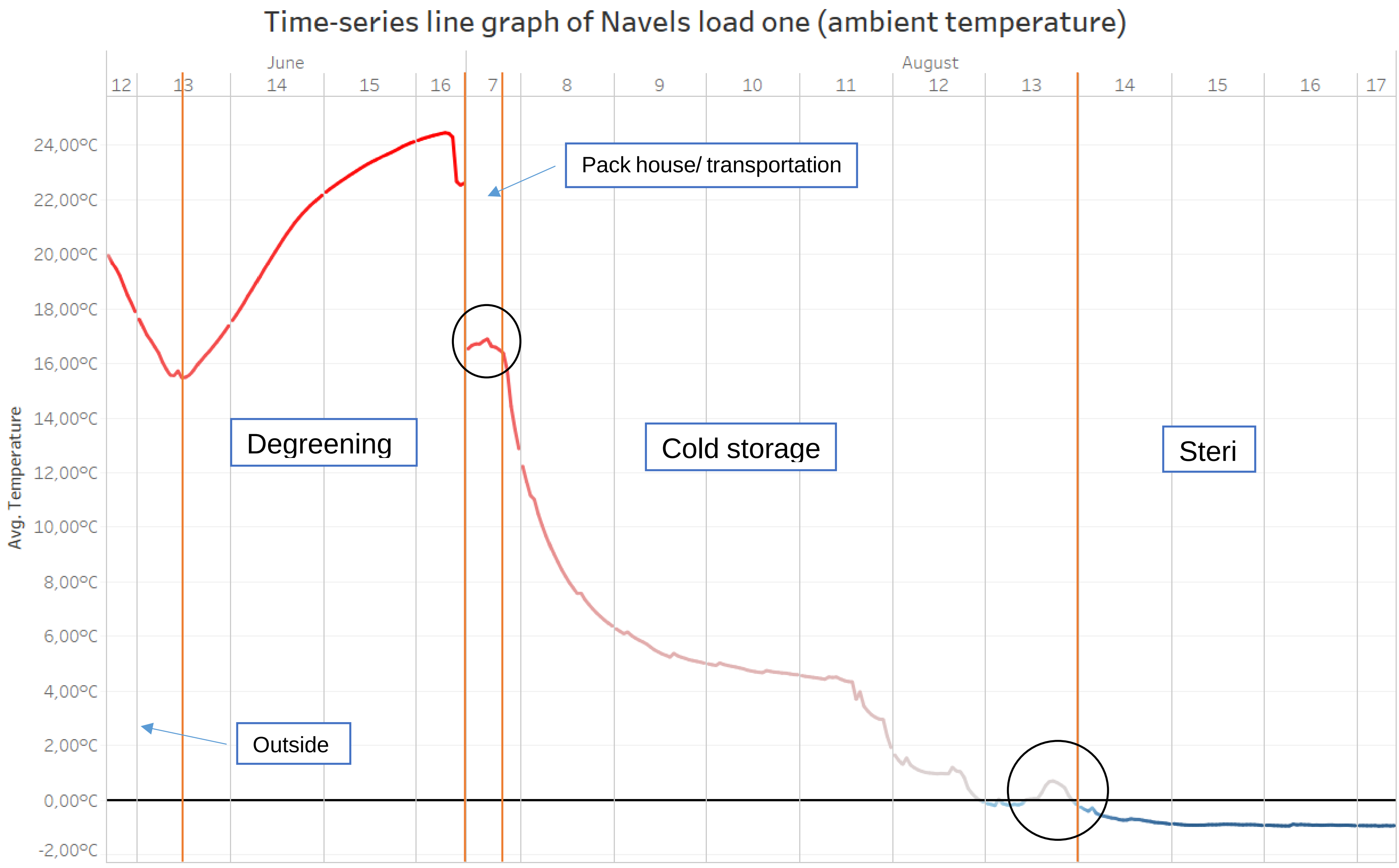

Figure 29: Time-series line graph of Navels load one – ambient

Table 8: Temperature dispersion per stage of Navels load one

	Outside stage		**Degreening stage**		**Pack house/ transportation stage**		**Cold storage stage**		**Steri stage**	
	Pulp	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**
Average	17.14°C	17.28°C	21.55°C	21.26°C	16.52°C	16.65°C	3.61°C	3.59°C	-0.97°C	-0.92°C
Median	17.33°C	17.22°C	22.65°C	22.17°C	16.51°C	16.75°C	4.09°C	3.96°C	-0.98°C	-0.99°C
Standard deviation	2.17°C	1.60°C	3.05°C	2.89°C	0.88°C	1.02°C	3.96°C	3.93°C	0.15°C	0.16°C
Minimum	11.65°C	13.81°C	13.64°C	13.93°C	14.26°C	13.27°C	-1.06°C	-1.32°C	-1.21°C	-1.37°C
Maximum	21.55°C	21.16°C	25.46°C	25.09°C	18.08°C	18.47°C	18.08°C	18.53°C	-0.55°C	-0.1°C

4.3.2.1.1 Outside stage

The Navels stood outside overnight, which the time-series graphs (Figure 28 and Figure 29) clearly illustrate. The temperature gradually drops as time progresses and gradually increases again once the degreening process initiates. Right before the degreening process initiates, there is a small temperature spike on the ambient temperature graph. The spike occurred mid-morning and is a result of the day temperatures' increase at that time. The spike was not prominent enough to influence the pulp temperature. As soon as the fruit enters the degreening room, which the outside temperatures did not affect yet, the ambient temperature dropped again until the degreening process started.

The rest of the outside stage was stable, with no temperature spikes / temperature breaks. There were some anomalies regarding the temperature dispersion. Firstly, the pulp temperature was more dispersed than the ambient temperature. It also reflected a lower average and minimum than the ambient temperature. This is, most likely, because these fruits kept their temperature from previous cooler conditions and did not react to the changes in temperature as rapidly as the ambient devices. Usually, it tends to be the other way around, because of fruit respiration. However, these anomalies should not have a negative influence on the citrus' quality. The median pulp is slightly higher than the median ambient temperature at 17.33ºC and 17.22ºC, which is normal. Figure 30 illustrates the temperature dispersion during the outside stage.

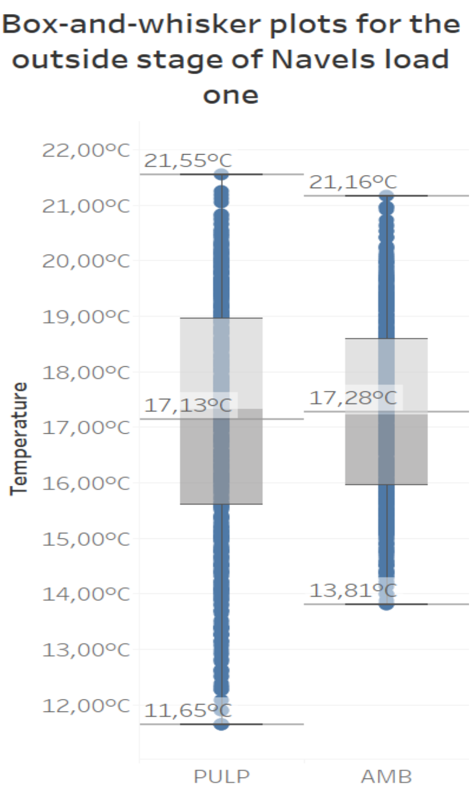

Figure 30: Box-and-whisker plots of Navels load one – outside

4.3.2.1.2 Degreening Stage

Both pulp and ambient temperatures were stable during the degreening stage, with no temperature breaks / temperature spikes occurring. The pulp and ambient box-and-whisker plots are highly similar during this stage. The pulp temperature was slightly more dispersed than the ambient temperature, which is an anomaly. The difference, however, is insignificant. Figure 31 illustrates the temperature dispersion during the outside stage.

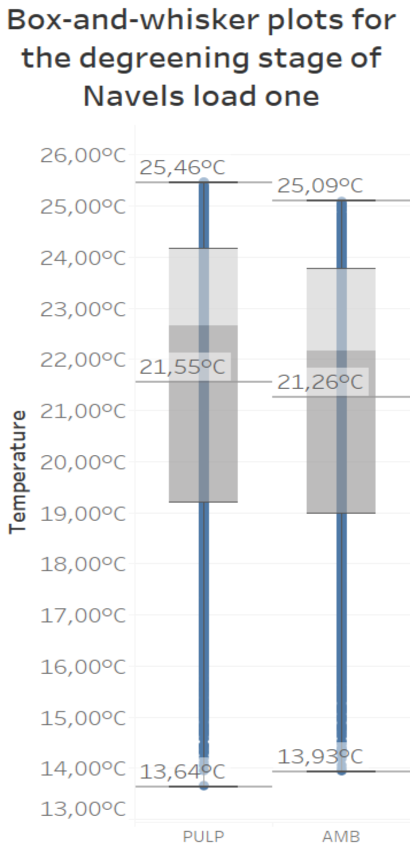

Figure 31: Box-and-whisker plots of Navels load one – degreening

4.3.2.1.3 Pack house/ transportation stage

The pack house/ transportation stage was fairly stable, especially during the pack house segment. There was a minor temperature spike towards the end of the transportation segment. The ambient temperature was significantly more dispersed than the pulp temperature, especially regarding the lower whiskers of the box-and-whisker plots. This is normal and is a result of fruit respiration.

Farm A dispatched the fruit during the morning, which is a colder time of day. Because of citrus' respiratory nature, the ambient monitors reacted more aggressively to the morning temperatures and are therefore, more dispersed. Figure 32 is a box-and-whisker diagram, illustrating the temperature dispersion during the pack house/ transportation stage of Navels load one.

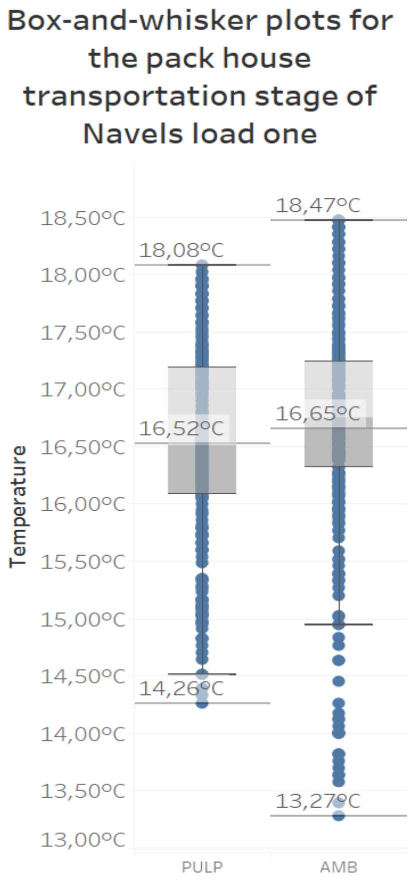

Figure 32: Box-and-whisker plots of Navels load one – pack house/ transportation

Temperature spike:

Towards the end of the stage, there was a slight temperature serge in 29 of the total 33 iButtons®. The section includes no box-and-whisker plots for the temperature spike as the temperature increased steadily during the entire trip as the day temperatures increased. Therefore, the box-and-whisker plots for the spike period is identical to Figure 32.

The highest pulp temperature increase during the temperature spike was PULP TOP 1 at 1.75°C, while the highest ambient temperature increase was AMB TOP 1 at 2.07°C. These two devices were situated in the same box, at the front of the tautliner trailer. This indicates that there may be a need for future research that investigates the influence of airflow inside a tautliner trailer on citrus fruits' temperature profile. None of the iButtons® met the criteria to qualify as temperature breaks.

There was a tendency throughout the study for temperature spikes to occur during this stage, when the farms dispatched the fruit mid-morning. The most probable cause for these temperature spikes is that the temperature inside the tautliner increases alongside the day temperatures, which influences the fruits' pulp and ambient temperatures. During a warmer time of day, this may cause problems regarding temperature breaks and quality. Table 9 illustrates the temperature dispersion during the temperature spike.

Table 9: Temperature dispersion of Navels load one – pack house and transportation temperature spike

	Pulp	**Ambient**
Average	16.52°C	16.65°C
Median	16.51°C	16.75°C
Average increase	0.50°C	0.75°C
Median increase	0.31°C	0.63°C
Standard deviation (*s*)	0.88°C	1.02°C
Minimum	14.26°C	13.27°C
Maximum	18.08°C	18.47°C

There were some positive signs during the cold storage stage of Navels load one, because there were no temperature breaks during inspection, like with the previous consignments. Normally, there are temperature spikes / temperature breaks during inspection, because it occurs at ambient temperature.

The box-and-whisker plots during the stage look similar, with the ambient temperature slightly more dispersed, which is normal. As explained in the previous two consignments, the maximum temperature appears to be high, because all the fruit did not enter cold storage at the same time. The pulp and ambient average and median temperatures fall within the normal cold storage range.

Overall, the temperature was stable during the cold storage stage, especially because there were no temperature breaks during inspection. However, the low minimum temperatures during the cold storage stage are an anomaly, because they are well below the normal cold storage range of 0-6°C. This may cause problems during the switchover from cold storage to Steri, as the outside temperatures may be well above the fruit's temperatures. This can cause the citrus' temperature to rise quicker than usual and lead to fruit respiration. Figure 33 illustrates the temperature dispersion during the cold storage stage.

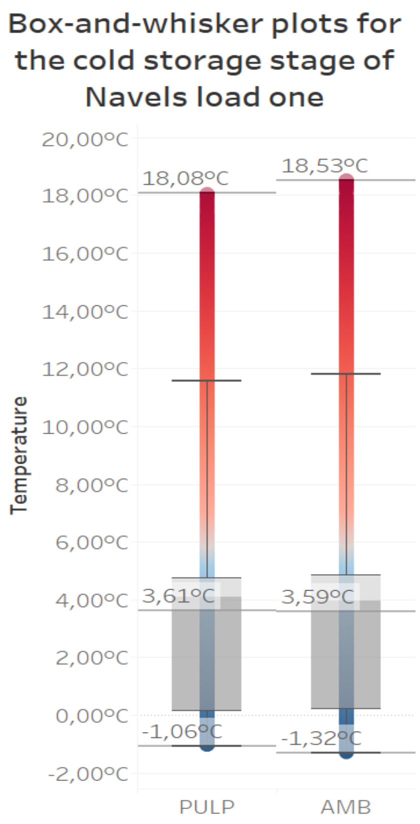

Figure 33: Box-and-whisker plots of Navels load one – cold storage

Temperature break:

At the end of the cold storage stage, all the iButtons® reflected an increase in temperature, with three devices confirmed as temperature breaks. They are PULP BOT 1, PULP BOT 3 and AMB BOT 1. The highest pulp temperature increase recorded was PULP BOT 3 at 2.76°C and the highest ambient temperature increase recorded was AMB BOT 1 at 2.83°C. Like the previous two consignments, the most probable cause is exposure to outside temperatures during the switchover from cold storage to Steri. Figure 34 and Table 10 illustrates the pulp and ambient temperature dispersion during the temperature break.

Table 10: Temperature dispersion of Navels load one – cold storage temperature break

	Pulp	**Ambient**
Average	0.33°C	0.39°C
Median	-0.06°C	0.13°C
Average increase	1.07°C	1.17°C
Median increase	0.82°C	0.88°C
Standard deviation (*s*)	0.50°C	0.54°C
Minimum	-0.48°C	-1.05°C
Maximum	2.54°C	3.08°C

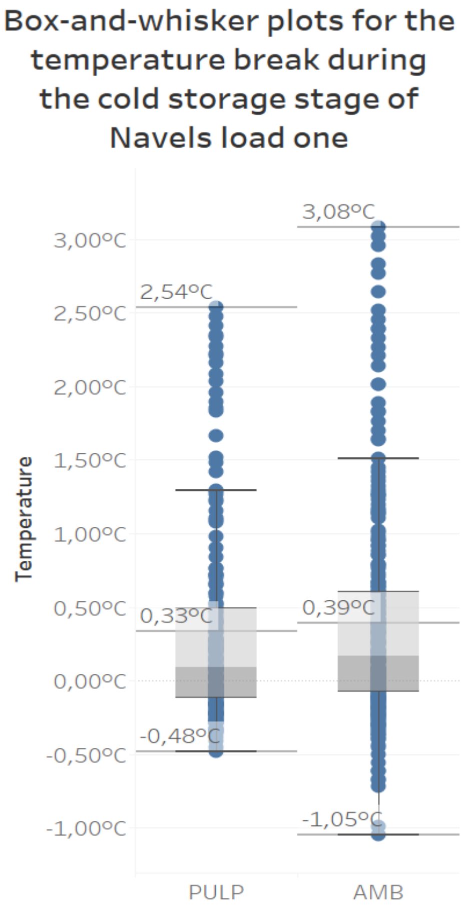

Figure 34: Box-and-whisker plots of Navels load one – cold storage temperature break

4.3.2.1.4 Steri stage

The temperature was stable during the Steri stage, with no temperature spikes / temperature breaks occurring. The ambient temperature is slightly more dispersed than the pulp temperature, which is normal. There is a single random high temperature recording of -0.1°C, but the temperature never breaches the 0°C barrier, and it is only one reading. The pulp temperature stays significantly above the -1.5°C CI threshold. The ambient temperature also never breaches the CI threshold, which is a positive sign. Figure 35 illustrates the temperature dispersion during the Steri stage.

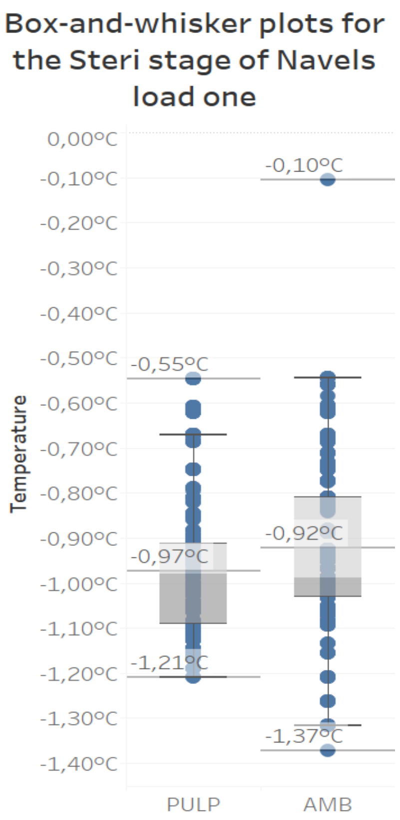

Figure 35: Box-and-whisker plots of Navels load one – Steri

4.3.2.1.5 Conclusion

<u>Outside stage:</u>

The temperature was stable during the outside stage. The ambient temperatures reflect a temperature spike right before the degreening stage, which is most likely a result of the increase in day temperatures, but it is not a concern and did not influence the pulp temperatures.

<u>Degreening stage:</u>

Like the first two consignments, the degreening stage was one of the most stable stages of Navels load one. The box-and-whisker plots looked similar for the pulp and ambient temperature and no temperature spikes or temperature breaks occurred.

<u>Pack house/ transportation stage:</u>

The pack house/ transportation stage reflected stable temperatures, with a minor temperature spike during the transportation segment. The ambient temperatures were significantly more dispersed than the pulp temperatures, especially regarding minimum values. This is most likely a result of the time of day that the truck departed.

The temperature spike during the transportation segment is a result of the day temperatures increasing during the voyage, but did not lead to any temperature breaks. The researcher identified an area for future research concerning a pallet's position in a tautliner's influence on citrus' temperature profile.

Cold storage stage:

There were no temperature breaks / temperature spikes during the inspection for Navels load one, which is a positive sign. The minimum temperatures are abnormally low and may cause problems during the switchover from cold storage to Steri.

At the end of the cold storage stage, all the devices reflected an increase in temperature. Three devices qualified as temperature breaks. The most probable cause of the temperature break is exposure to outside temperatures during the switchover from cold storage to Steri.

Steri stage:

The Steri stage reflected stable temperatures, with no temperature spikes / temperature breaks during the stage. There was a single high recording of -0.1°C, but the temperature did not breach the 0°C barrier. The ambient temperature came close to the CI threshold, but ever breached it, while the pulp temperature stayed well above the CI threshold.

4.3.2.2 LOAD TWO – FARM A

The second consignment of Navels was the fourth and final trial. This trial took place from Farm A and, as mentioned in the previous section, its degreening occurred alongside the Navels from the first consignment. Because the researcher repeated the first trial, load two's pack house/ transportation stage occurred before Navels load one's.

The researcher probed the fruit on 03/07/2018 at Farm A for the pack house/ transportation segment and the iButtons® activated at 16:00 on that same day. The pack house/ transportation stage for this consignment was short as Company K placed the fruit in cold storage almost immediately after their arrival. It lasted for four hours.

On 03/07/2018 the fruit arrived at Company K, who unloaded the pallets and placed them in cold storage shortly thereafter. The citrus remained in cold storage for an extended period, as a result of delays in the shipping schedule. As a result, this stage lasted for approximately five days. These delays cause problems for Company K, because they must accommodate the same amount of fruit as usual with less time and space.

At 12:00 on 08/07/2018 the Steri stage was completely initiated and all the citrus' temperatures were below -0.6°C for the first time. The fruit remained in the Steri chambers for three days.

At 09:00 on 11/07/2018 the researcher removed the citrus from the Steri chambers, and the final trial ended.

Figures 36 and 37 are time-series line graphs illustrating the temperature profile of Clementines load two. The vertical orange lines indicate when the outside/degreening stage, pack house/ transportation stage and cold storage stage end, with the last stage being the Steri-protocol stage. The circles on the graph indicate the relevant temperature breaks and temperature spikes, discussed in the following sub-sections. Table 11 contains the dispersion of temperatures during each stage.

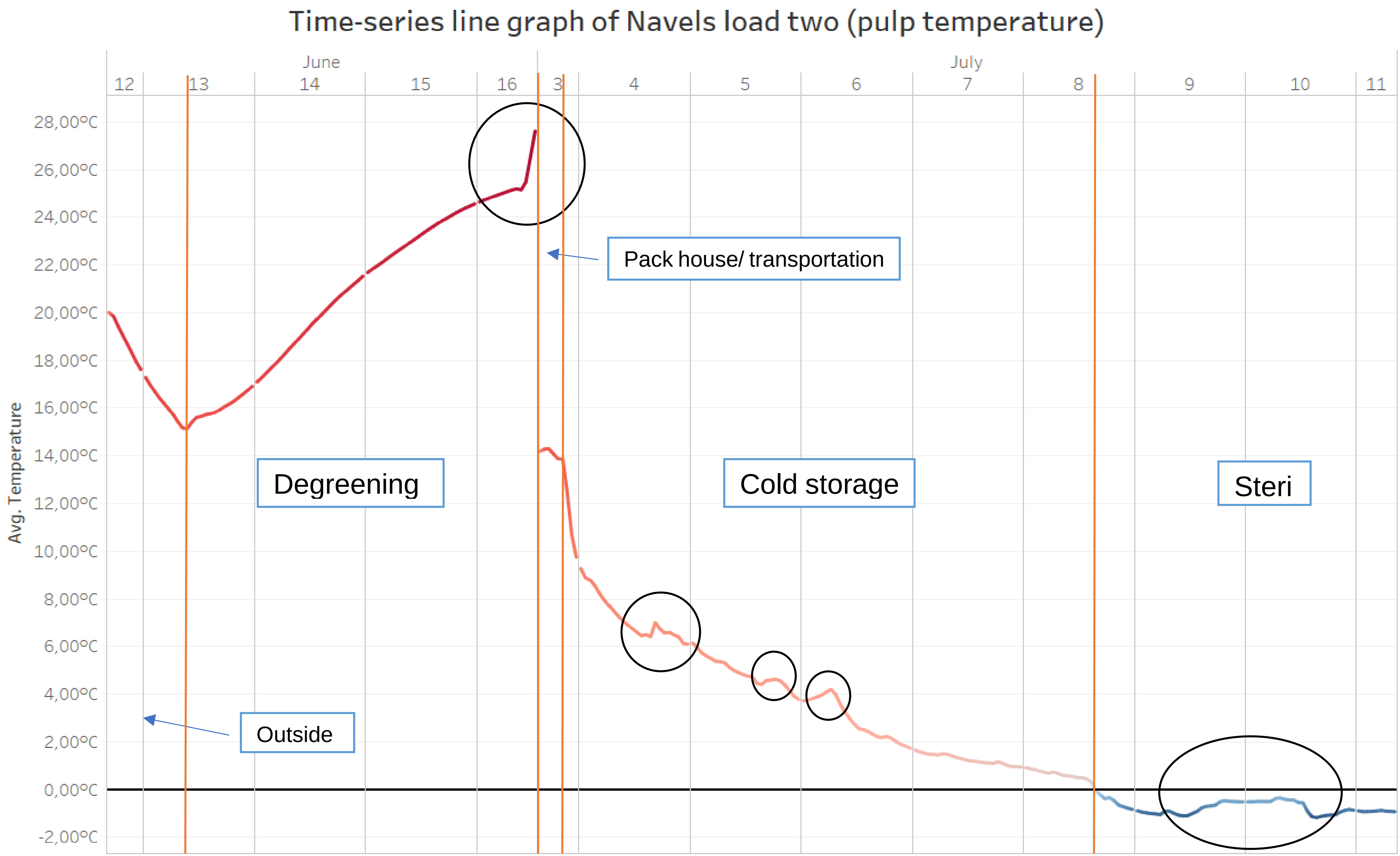

Figure 36: Time-series line graph of Navels load two – pulp

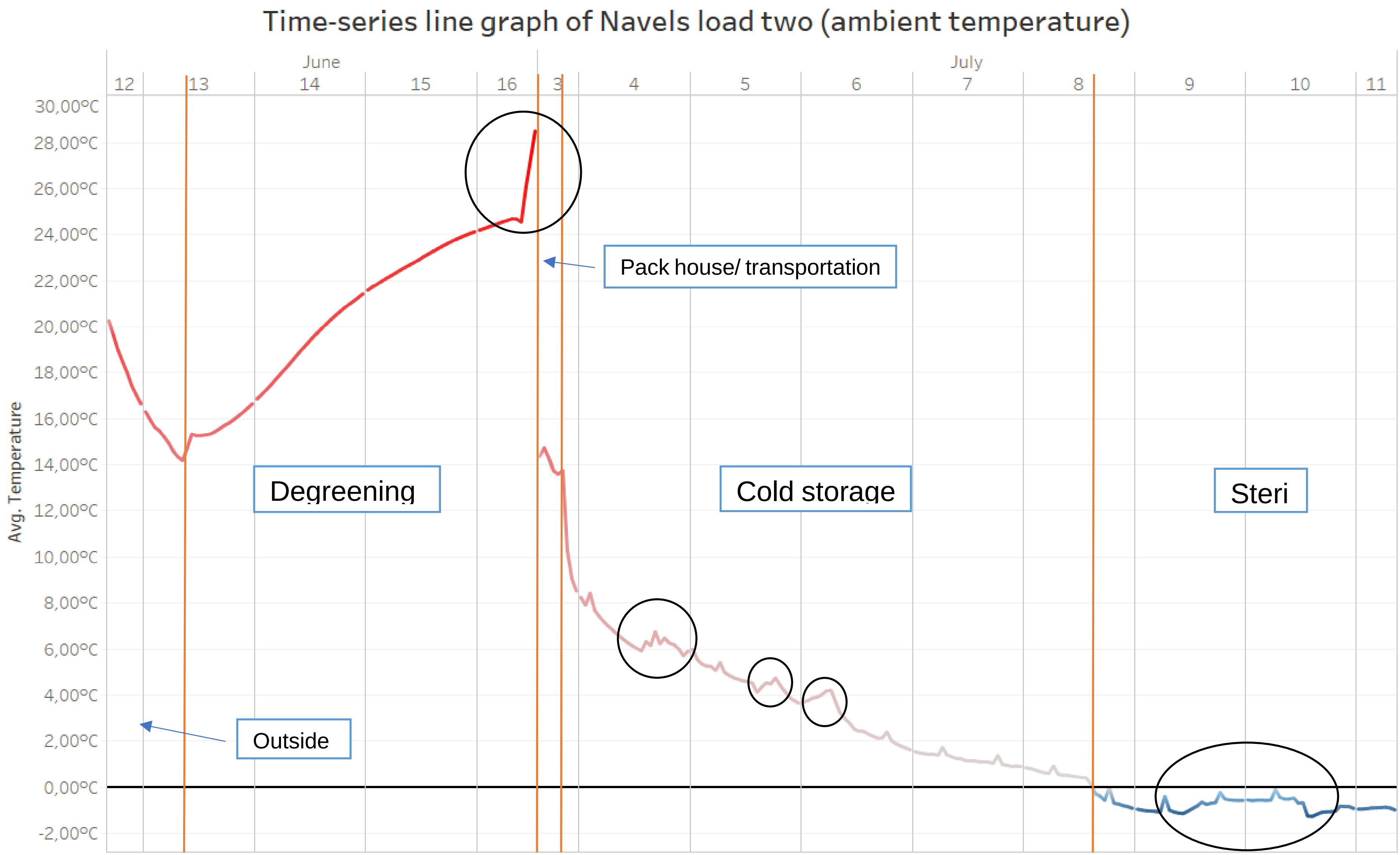

Figure 37: Time-series line graph of Navels load two – ambient

Table 11: Temperature dispersion per stage of Navels load two

	Outside stage		Degreening stage		Pack house/ transportation stage		Cold storage stage		Steri stage	
	Pulp	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**
Average	17.03°C	16.30°C	21.20°C	21.00°C	14.13°C	14.12°C	3.59°C	3.36°C	-0.79°C	-0.81°C
Median	17.36°C	16.33°C	21.72°C	21.65°C	14.26°C	14.24°C	3.15°C	2.89°C	-0.86°C	-0.87°C
Standard deviation	2.05°C	2.16°C	3.34°C	3.47°C	0.80°C	0.98°C	3.18°C	2.94°C	0.29°C	0.31°C
Minimum	12.13°C	11.26°C	14.21°C	13.57°C	12.14°C	12.3°C	-1.06°C	-1.05°C	-1.37°C	-1.5°C
Maximum	20.89°C	21.10°C	35.11°C	42.86°C	15.57°C	16.54°C	15.13°C	15.02°C	0.20°C	0.68°C

4.3.2.2.1 Outside stage

The outside stage for Navels load two is the same as Navels load one, because it occurred simultaneously. Therefore, this section is shorter than usual. Like load one, the outside stage reflected stable temperatures. When the iButtons® activate, the temperature continuously drops as time progresses. This is a result of the time of day, as the citrus were probed at 17:00 on 12/06/2018. The ambient temperature is slightly more dispersed than the pulp temperature, as expected. The box-and-whisker plots in Figure 38 illustrate the temperature dispersion during the degreening stage.

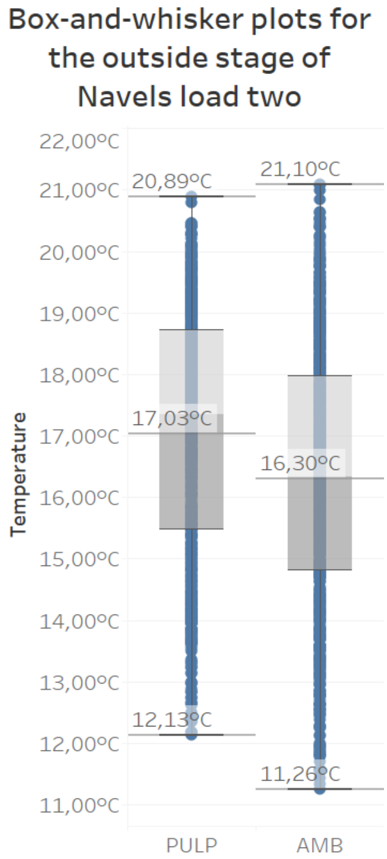

Figure 38: Box-and-whisker plots of Navels load two – outside

4.3.2.2.2 Degreening stage

For most of the degreening stage, the temperature was stable, staying within the normal degreening range. As expected, the ambient temperature was more dispersed than the pulp temperature, because ambient monitors react more aggressively to temperature changes. The box-and-whisker plots in Figure 39 illustrate the temperature dispersion during the degreening stage.

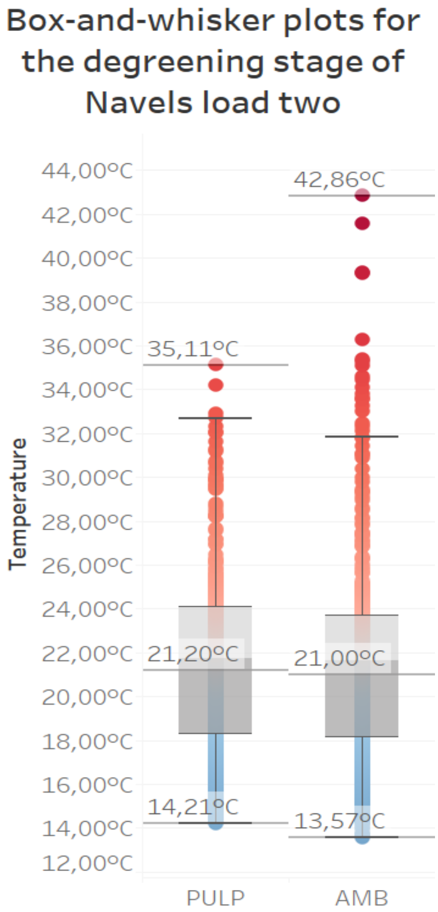

Figure 39: Box-and-whisker plots of Navels load two – degreening

Temperature spike:

Towards the end of the degreening stage, there was a substantial temperature surge, with several iButtons® recording temperatures that were significantly higher than the normal degreening bracket of 20-25°C. In order to construct the box and whisker plots and table of dispersion for the temperature spike period, the researcher extracted all the temperatures from when the first monitor started recording temperatures above the maximum recommended temperature in the degreening bracket, which is 25°C.

Figures 36, 37, 39 and 40 and Tables 11 and 12 all reflect concerning values regarding the degreening stage. On average, the pulp temperature increased above the recommended maximum temperature for degreening by 4.10°C while the ambient temperature did so by 7.06°C, which are substantial increases. The median pulp and ambient temperature increases followed the same trend at 5.06°C and 6.58°C respectively. The maximum pulp and ambient temperature during the temperature spike were 35.11°C and 42.86°C. These temperatures are dangerously high and may have profoundly negative effects on citrus' quality. The median pulp and ambient temperatures fell within the degreening bracket at 21.72°C and 21.65°C, which indicated that the maximum temperatures during the temperature surge were high enough to significantly increase the average temperatures.

With the assistance of a citrus expert from Stellenbosch University's horticultural department, Prof Paul Cronjé, the researcher determined that the most probable cause of the temperature spike was fruit respiration. Prof Cronjé explained that these types of temperature surges are the reason why several industry experts oppose the degreening procedure. He clarified that it leads to abnormal fruit respiration and moisture loss, which shortens the fruits' shelf-life and downgrades the quality. Table 12 and figure 40 illustrate the pulp and ambient temperature dispersion during the temperature spike.

Table 12: Temperature dispersion of Navels load two – degreening temperature spike

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

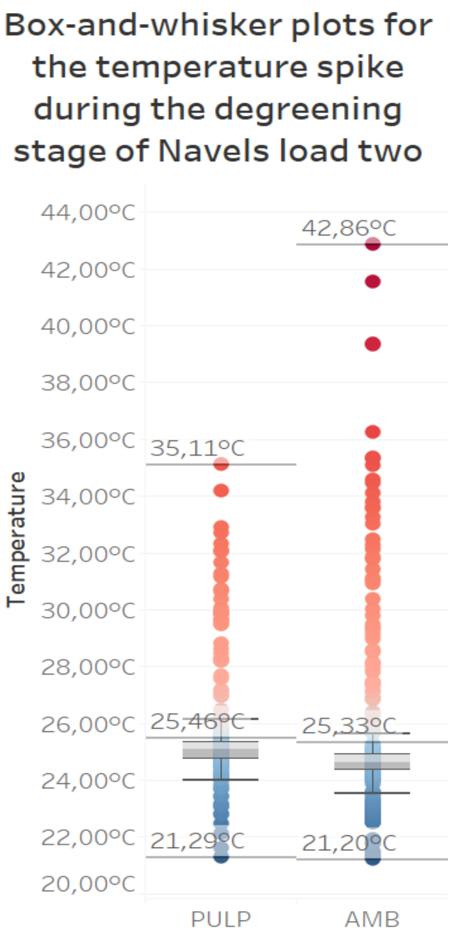

Figure 40: Box-and-whisker plots of Navels load two – degreening temperature spike

4.3.2.2.3 Pack house/ transportation stage

The pack house/ transportation stage was stable, with a minor temperature spike during the beginning of the voyage. The ambient temperature was slightly more dispersed than the pulp temperature, especially regarding the higher temperatures. The box-and-whisker plots in Figure 41 illustrate the temperature dispersion during the pack house/ transportation stage.

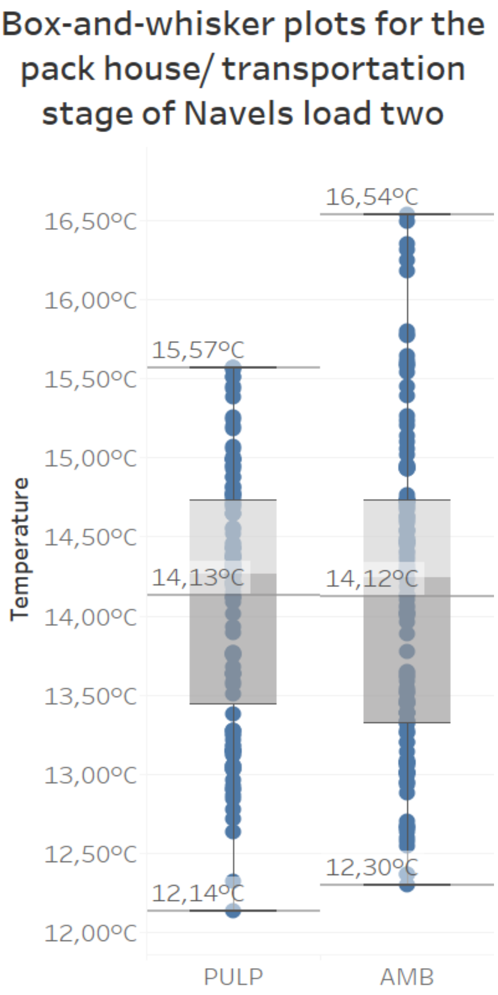

Figure 41: Box-and-whisker plots for Navels load two – pack house/ transportation

Temperature spike:

The most probable cause of the temperature spike is the absence of airflow inside the tautliner. Tautliners are closed trailers and don't contain openings, which means that there is no through-flow of fresh air during the voyage. This, coupled with the sunlight exposure to the trailer, caused the trailer to be slightly warmer than the outside. As the temperature drops at the end of the day, the iButtons® also reflect a temperature drop. The ambient temperature reacted significantly more aggressively to the temperature spike, but none of the devices qualified as temperature breaks during the period. Table 13 illustrates the pulp and ambient temperature dispersion during the temperature spike.

Table 13: Temperature dispersion of Navels load two – pack house/ transportation temperature spike

	Pulp	**Ambient**
Average	14.13°C	14.12°C
Median	14.26°C	14.24°C
Average increase	0.26°C	0.56°C
Median increase	0.19°C	0.44°C
Standard deviation (*s*)	0.80°C	0.98°C
Minimum	12.14°C	12.30°C
Maximum	15.57°C	16.54°C

4.3.2.2.4 Cold storage stage

The temperature was not convincingly stable during this consignment's cold storage stage, which contained a temperature break and two temperature spikes. This triggered a possible need for further research that investigates the influence of temperature anomalies during the logistical practices before the cold chain is initiated on the temperature profile of citrus fruits while they are in the cold chain. The pulp and ambient temperatures were significantly similar regarding dispersion and differed by a small fraction of a degree in each case. Both pulp and ambient averages and medians fall within the normal cold storage bracket of 0°C - 6°C. The minimum temperatures are low, because the fruit did not enter Steri at the same time. Figure 42 illustrates the temperature dispersion during this stage.

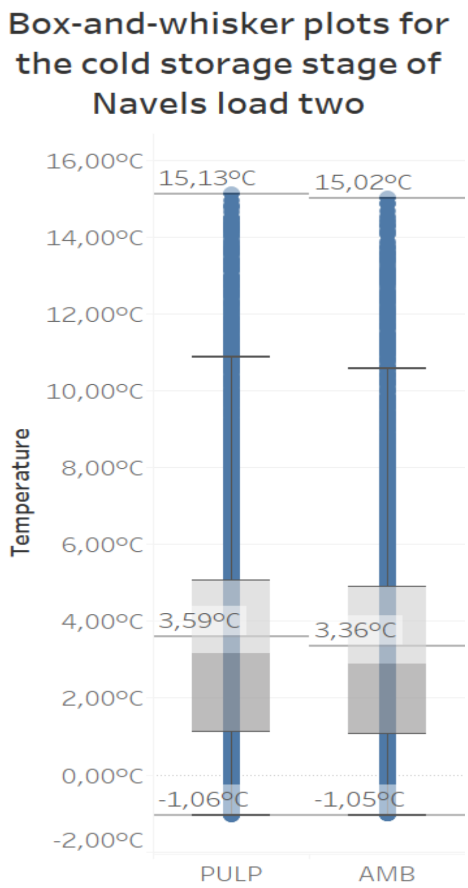

Figure 42: Box-and-whisker plots of Navels load two – cold storage

Temperature break and temperature spikes:

As mentioned earlier in this section, there was a temperature break at the beginning of the stage, followed by two temperatures breaks in quick succession. This section discusses these anomalies. Table 14 illustrates the pulp and ambient temperature dispersion of the temperature breaks and temperature spikes during the cold storage stage.

Table 14: Temperature dispersion of Navels load two – cold storage temperature break and temperature spikes

	Temperature break		**First temperature spike**		**Second temperature spike**	
	Pulp	**Ambient**	**Pulp**	**Ambient**	**Pulp**	**Ambient**
Average	6.42°C	6.11°C	4.37°C	4.24°C	3.92°C	3.92°C
Median	5.86°C	5.64°C	4.34°C	4.25°C	3.91°C	3.88°C
Average increase	1.19°C	1.78°C	0.74°C	1.05°C	0.52°C	0.70°C
Median increase	1.10°C	1.98°C	0.78°C	1.13°C	0.56°C	0.69°C
Standard deviation (*s*)	1.86°C	1.58°C	0.51°C	0.51°C	0.21°C	0.23°C
Minimum	3.51°C	3.52°C	3.16°C	2.85°C	3.47°C	3.44°C
Maximum	11.76°C	11.07°C	6.08°C	5.65°C	4.45°C	4.65°C

The temperature break reflected higher pulp temperatures than ambient temperatures. The average, median and maximum pulp temperatures during this period was higher than the ambient temperatures, which is mostly a result of fruit respiration. The minimum temperatures are almost identical. The pulp *s*-value is slightly higher than the ambient temperature, which is an anomaly. Figure 43 illustrates the temperature dispersion during the temperature break. The most probable reason for the temperature break is either exposure to outside air during inspection or transferral between cold stores during stowage.

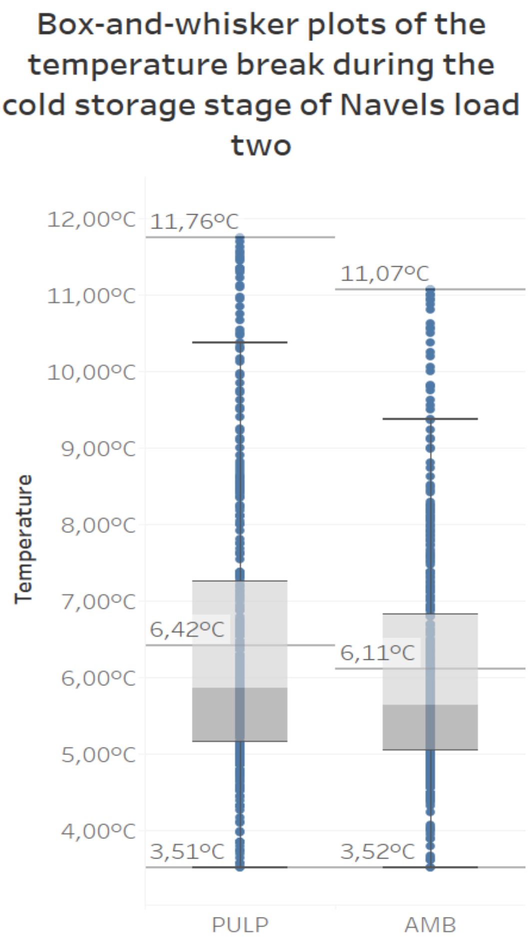

Figure 43: Box-and-whisker plots of Navels load two – cold storage temperature break

The first temperature spike occurred approximately one day after the temperature break. The pulp temperatures were higher than the ambient temperatures for each measure of dispersion. This is most likely a result of fruit respiration. The *s*-values during the temperature break are the same, which is an anomaly that resulted from unknown reasons. Normally, the ambient *s* is higher than the pulp *s*.

The most probable cause for the temperature spike is the same as for the temperature break – exposure to outside air during inspection or transferral between cold stores during stowage. The box-and-whisker plots in Figure 44 illustrate the temperature dispersion during the temperature spike.

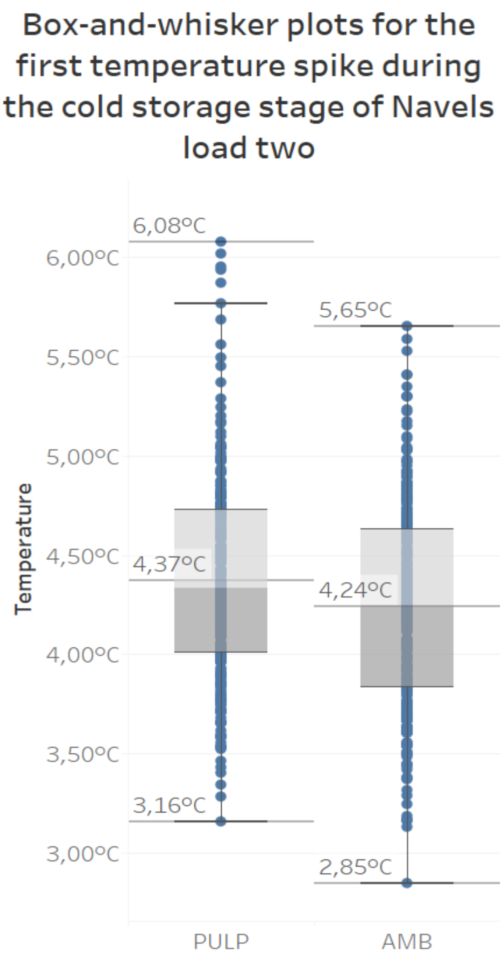

Figure 44: Box-and-whisker plots of Navels load two – cold storage first temperature spike

As soon as the temperature stabilized after the first temperature spike, another temperature spike occurred. The ambient temperature was slightly more dispersed than the pulp temperature during the temperature spike, because ambient monitors respond to temperature changes more aggressively. However, the differences are insignificant.

The averages are exaclty the same, with the ambient temperatures having a higher maximum and a lower minimum. The average and median ambient temperature increases are higher than the pulp increases. The *s*-values are very similar, with the ambient *s* slightly higher. The difference, however, is insignificant.

The most probable cause for the temperature spike is exposure to outside air during inspection or transferral between cold stores during stowage. These are the same reasons as with the two previous temperature increases. It is difficult to determine whether the inspection or transferral between cold stores occurred first. They are, however, the two main suspected causes for the temperature increases. Figure 45 illustrates the temperature dispersion for the second temperature spike during the cold storage stage of Navels load two.

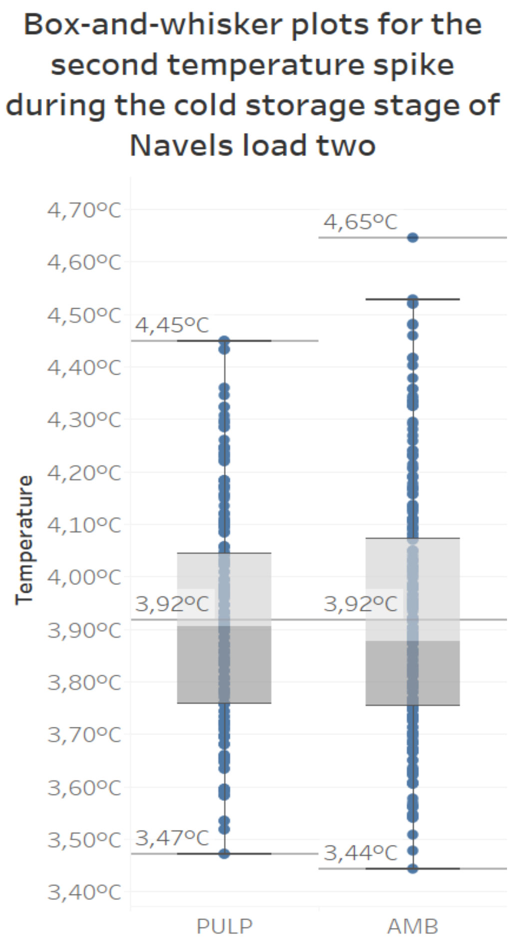

Figure 45: Box-and-whisker plots of Navels load two – cold storage second temperature spike

4.3.2.2.5 Steri stage

Navels load two displayed further problems during the Steri stage. As expected, the ambient temperatures were more dispersed than the pulp temperatures. The minimum ambient temperature breached the CI threshold of -1.50°C, but only by 0.01°C. The pulp temperature, however, never breached the threshold, which is a positive sign. Both average and median temperatures are below the recommended Steri bracket of -0.6°C. Figure 46 illustrates the temperature dispersion during the Steri stage.

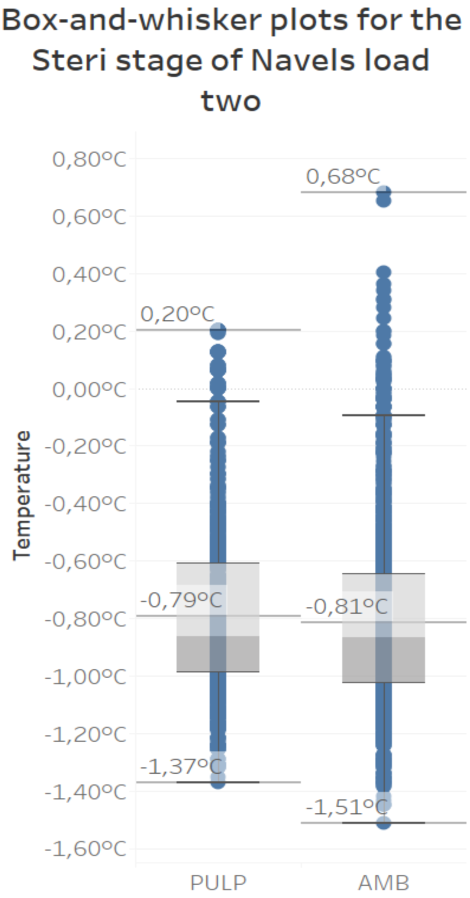

Figure 46: Box-and-whisker plots of Navels load two – Steri

Temperature spike:

At around 10:30 on 09/07/2017 the temperature of all the pulp and ambient temperature monitors started increasing. There were no temperature breaks during the period with the highest recorded temperature increase being 1.32°C for the pulp temperatures and 1.38°C for the ambient temperatures. As expected, the ambient temperatures were more dispersed during the temperature spike than the pulp temperatures. There are, however, other concerning values during the period that the temperatures increased.

As Table 15 and Figure 47 illustrate, the maximum pulp and ambient temperatures during the period are concerning. Both went above the 0°C threshold, which would normally lead to an extra 24 hours in the Steri chambers as per order of the US government. The maximum pulp temperature was 0.20°C during the period and the maximum ambient temperature was 0.31°C. For unknown reasons, Company K did not re-cool the citrus for 24 hours.

The most probable cause for the temperature spike is poor cold chain management by Company K, most likely as a result of delays in the shipping schedule. This placed pressure on the facility to increase the through-flow, which resulted in loss of complete temperature control in the Steri chambers. Table 15 and Figure 47 illustrate the temperature dispersion during the temperature spike.

Table 15: Temperature dispersion of Navels load two – Steri temperature spike

	Pulp	**Ambient**
Average	-0.62°C	-0.63°C
Median	-0.61°C	-0.65°C
Average increase	0.84°C	1.17°C
Median increase	0.82°C	1.13°C
Standard deviation (*s*)	0.31°C	0.30°C
Minimum	-1.37°C	-1.29°C
Maximum	0.20°C	0.31°C

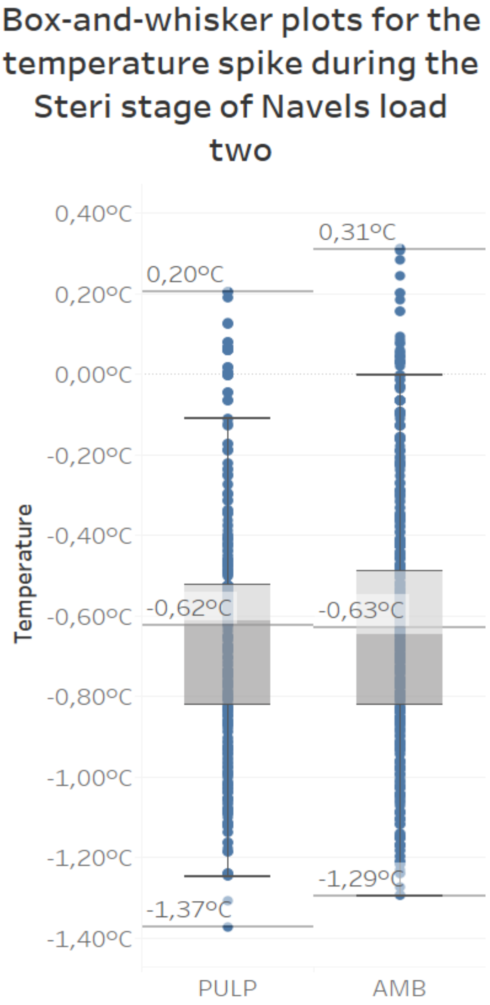

Figure 47: Box-and-whisker plots of Navels load two – Steri temperature spike

4.3.2.2.6 Conclusion

<u>Outside stage:</u>

Like Navels load one, the temperature was stable during the outside stage. The temperatures decreased gradually as after the iButtons® activated as a result of the time of day. The ambient temperatures were slightly more dispersed than the pulp temperatures.

Degreening stage:

The degreening temperatures were stable for most of the stage, until there was a substantial temperature increase towards the end of the stage. The maximum pulp and ambient temperatures during the increase were 35.11°C and 42.86°C, which is significantly higher than the recommended degreening bracket of 20-25°C and can have profoundly negative effects on citrus' quality, because it rapidly increases fruit respiration.

The most probable cause of the temperature spike was fruit respiration towards the end of the stage. Prof Paul Cronjé from Stellenbosch University's Department of Horticulture explained that this is one of the reasons why many experts are opposing the degreening process.

Pack house/ transportation stage:

The pack house/ transportation stage only reflected a minor temperature spike at the beginning of the stage, which was most likely a result of insufficient airflow inside the tautliner. The ambient temperature was slightly more dispersed than the pulp temperature.

Cold storage stage:

There were three temperature increase periods during the cold storage stage of Navels load two. This suggests that there may be a need for future research that investigates the influence of logistical practices before the cold chain is initiated on the temperature profile of citrus when they are in the cold chain.

The most probable causes of all three the anomalies were either exposure to outside temperatures during inspection or transferral between cold stores, as the researcher does not know which of these occurred first. Surprisingly, there were no temperature spikes or temperature breaks during the citrus' transferral from the cold stores to the Steri chambers.

Steri stage:

There was a prolonged temperature increase during the Steri stage of approximately one day. The most probable cause of the temperature spike is poor cold chain management as a result of pressure created by delays in the shipping schedule. Fortunately, none of the temperature spikes resulted in temperature breaks.

However, there are other concerning values during this period. Several pulp and ambient temperatures exceed the re-cooling threshold of 0°C. For unknown reasons, none of the pallets underwent the expected re-cooling process of 24 hours.

4.4 RESEARCH RELIABILITY AND VALIDITY

The most prominent criteria for evaluating the dependability of research are reliability and validity (Bryman & Bel, 2015). This implies that the research is valid and that the results that a study obtained are accurate.

The reliability of this research's results is supported its test-retest ability, when compared to previous studies of the same nature. The results of this study share many similarities to the previous studies that researchers have conducted in the field, as mentioned in Section 2.10 of the literature review (Chapter 2). When comparing its findings to Khumalo (2018), Valentine & Goedhals-Gerber (2017), Goedhals-Gerber *et al.* (2015), Freiboth *et al.* (2013), Haasbroek (2013) and Freiboth (2012), certain results are profoundly similar and various trends are evident, which strengthens the reliability of the research.

The validity of this research is supported by content validity and concurrent validity. The fact that the previous studies from the literature review (Chapter 2) and industry experts that were involved with this study developed the variables and constructs for the research provides sufficient content validity. In addition, Company J, who proposed the study, work in the industry daily, which further supports the content validity. The feedback from the entities involved in the study when they obtained the results proved the concurrent validity of the research.

CHAPTER 5: INTERPRETATION

5.1 INTRODUCTION

This chapter interprets the results of the data analysis. In Chapter 4 the study analysed the data by identifying temperature breaks and calculating the measures of central tendency and measures of dispersion. Chapter 5 identifies the main findings of the study as well as the reasons for these findings.

5.2 MAIN FINDINGS OF THE STUDY

5.2.1 OUTSIDE STAGES

The outside stages of all four consignments were the only stages that did not reflect any problems. For both consignments of Clementines, there were no temperature spikes while the citrus stood outside, which indicates that Farm A implemented consistent logistical practices that are advantageous for citrus quality. For the outside stages of both consignments of Navels, the temperature was stable again. There was a minor temperature spike in the ambient temperatures of Navels load two, because the fruit stood outside overnight and the temperature increased again in the morning hours. This temperature increase, however, was not significant enough to influence the pulp temperature.

The researcher could not collect a substantial amount of data regarding the outside stage on the farm. Farm A insisted that it was not possible to monitor the orchard part of the supply chain, because the citrus do not spend a large amount of time there. Collecting orchard data would also significantly complicate the farm's logistics. Further research that specifically investigates temperature breaks in the orchard and underway to the pack houses can be valuable for the industry.

5.2.2 DEGREENING STAGES

Farm A was consistent with its implementation of the degreening process throughout all four consignments. For the predominant part of the data that this study collected, the temperature was stable during the degreening process. This indicates that Farm A implements efficient degreening practices that are coherent with industry standards.

Despite Farm A's impressive performance regarding the degreening process, there was a concerning irregularity during the final phase of the degreening stage of Navels load two. Figures 36 and 37 indicate substantial increases during this period, with numerous pulp and ambient temperatures rising significantly higher than the prescribed degreening temperature. During any stage of the citrus export chain, temperatures of such magnitude can have debilitating effects on the quality and shelf-life of the fruit.

5.2.3 PACK HOUSE/ TRANSPORTATION STAGES

The pack house segment of the pack house/ transportation stage reflected stable temperatures for all four consignments. This means that Farm A and B implemented efficient logistical practices while the citrus resided on their premises. No temperature breaks occurred during this segment of the export chain for any of the four consignments, because Farm A and B kept the fruit in cool and shaded areas until the trucks arrived.

The end of the pack house segment of the pack house/ transportation stage marks the point where the farms no longer have control over the citrus. For this study, the farms outperformed the rest of the export chain significantly in terms of cold chain stabilization, because most of the irregularities occurred after the pack house segment.

Each consignment contained temperature irregularities during the transportation segment of the pack house/ transportation stage. During each load, the temperature of most of the devices increased after the trucks departed from the pack houses. While these temperature spikes only lead to three temperature breaks (all three during load two), it is still concerning, because the study took place during a cooler part of the year. Hence, during a warmer time of year, the number of temperature breaks may increase.

5.2.4 COLD STORAGE STAGES

Once the citrus entered the cold chain, the number of irregularities increased significantly. The iButtons® detected several temperature spikes and temperature breaks during each consignment's cold storage stage. In most cases, there is in initial temperature spike/ temperature break during the inspection stage, followed by another temperature spike/ temperature break during the switchover from cold storage to the Steri chambers.

5.2.5 STERI STAGES

Only one consignment, Navels load one, demonstrated stable temperatures during the Steri process. The other three contained irregularities. Temperature spikes occurred during Clementines load one and Navels load two. Several devices indicated temperatures below the CI threshold of -1.5°C during Clementines load one and Clementines load two. This study did not identify any temperature breaks during the Steri protocol of any of the consignments, which is a positive sign.

5.2.6 CONCLUSION

Evidently, temperature anomalies occurred along each segment of the South African leg of the export cold chain. The farm segment (outside stage, degreening stage and pack house part of the pack house/ transportation stage) ran efficiently and outperformed the rest of the supply chain significantly, with the only anomaly being the temperature spike during the degreening stage of Navels load two. The rest of the supply chain (transportation and onwards) performed poorly and requires improvement for South Africa to remain competitive in the international market. Table 16 summarizes the main findings of the study.

Table 16: Summary of the main findings identified by the study

Finding	
1.	Significant temperature spikes during degreening stage of Navels load two.
2.	Several temperature spikes occurred during the transportation segment of the pack house/ transportation stage for each consignment. These temperature spikes led to ambient temperature breaks during Clementines load two's transportation segment.
3.	Several temperature breaks and temperature spikes occurred during inspection in the cold storage stage.
4.	Several temperature breaks and temperature spikes occurred during the switchover from cold storage to the Steri chambers.
5.	Several temperature spikes occurred during Steri stages of three consignments.
6.	During Clementines load one and Clementines load two, several temperatures fell below the CI threshold of -1.5°C.

5.3 CAUSES OF/ REASONS FOR THE MAIN FINDINGS OF THE STUDY

5.3.1 FINDING ONE – TEMPERATURE SPIKE DURING DEGREENING

After consulting Prof Paul Cronjé from the Department of Horticulture, the researcher identified that the most probable cause of the temperature spike was fruit respiration. Prof Cronjé explained that the degreening process accelerates fruit respiration, because it occurs in warm temperatures inside the chamber. This respiration sometimes goes out of control. Many industry experts are against the degreening process for this reason.

5.3.2 FINDING TWO – TEMPERATURE INCREASES DURING THE TRANSPORTATION SEGMENT OF THE PACKHOUSE/ TRANSPORTATION STAGE

These temperature increases occurred during each consignment and led to three ambient temperature breaks during Clementines load two. Farms utilise tautliner trailers to transport the citrus from Citrusdal to Company K. There are no ventilation systems or temperature control procedures in these trailers. This leads to insufficient airflow during the voyage to Cape Town. When the trucks depart from the pack houses, the trailers are exposed to outside air temperatures as well as sunlight. This exposure caused the temperature to increase each time. At the beginning and end of the season, when day temperatures are warmer, this problem may become increasingly concerning.

5.3.3 FINDING THREE – TEMPERATURE BREAKS AND SPIKES DURING INSPECTION IN THE COLD STORAGE STAGE

Temperature breaks and temperature spikes during inspection trended throughout the study. Inspection occurs at ambient temperature. In other words, the inspectors remove the citrus from cold storage and inspects the fruit outside. The temperatures outside are significantly higher than the temperatures inside the cold store (to which the citrus have already acclimatized). Therefore, the outside temperatures quickly influence the fruits' temperature, which lead to temperature breaks and temperature spikes.

5.3.4 FINDING FOUR – TEMPERATURE BREAKS AND TEMPERATURE SPIKES DURING THE SWITCHOVER FROM COLD STORAGE TO STERI

Before Company K initiates the Steri protocol, they remove the fruit from the cold store and move it to specialized Steri chambers next to the quayside. Like with inspection, a period of exposure to ambient temperatures occurs. The ambient temperatures are significantly higher than cold store temperatures and quickly influence the citrus' temperatures. Only the last consignment did not experience temperature increases during this segment.

5.3.5 FINDING FIVE – TEMPERATURE SPIKES DURING THE STERI PROTOCOL

Usually, temperature increases during the Steri protocol result from poor cold chain management. Influences from outside rarely occur, because staff may not open the chambers during the protocol. For instance, during Clementines load one, management let the temperature inside the chamber drop too low, forcing them to react quickly in order to increase the temperature. They increased the temperature too aggressively, which caused a temperature spike. During Navels load two, delays in the shipping schedule placed pressure on Company K to accommodate a larger through flow than usual, which led to mismanagement.

5.3.6 FINDING SIX – TEMPERATURES FALLING BELOW THE CI THRESHOLD DURING THE STERI PROTOCOL

When temperatures fall below the CI threshold, it is also a result of poor cold chain management. Usually, this happens because the delivery air is set below the CI threshold temperature to cool the room down as quickly as possible. This causes many of the citrus' temperatures to move dangerously close to, or even below the CI threshold. Pallets that are within a close proximity to the delivery vents are especially vulnerable to CI when this happens.

5.3.7 CONCLUSION

This section identified possible causes for the irregularities that the study detected. Knowing the reasons for these problems is a step in the right direction and may benefit the different role players in South African leg of the citrus export chain from Citrusdal to the USA. Table 17 summarizes the possible reasons for the temperature irregularities that the study identified.

Table 17: Reasons for the main findings that the study identified

Finding	Reason
1.	Degreening process accelerates fruit respiration, which becomes out of control.
2.	Insufficient airflow inside tautliner makes the citrus vulnerable to temperature increases.
3.	Inspection occurs at ambient temperature and causes citrus' temperature to increase.
4.	Exposure to ambient temperature during switchover from Cold storage to Steri chambers causes citrus' temperature to increase.
5.	Poor cold chain management causes temperature increases during Steri.
6.	Poor cold chain management leads to temperatures falling below the CI threshold during Steri.

5.4 CONCLUSION

The South African leg of the citrus export chain from SA to the USA is underperforming compared to its full potential and that certain adjustments can increase SA's competitiveness.

CHAPTER 6: CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

6.1 CONCLUSIONS

6.1.1 INTRODUCTION

This section determines whether the literature review, data analysis and interpretations chapters, as well as the recommendations section, achieved their goals.

6.1.2 DID THE STUDY MEET THE RESEARCH OBJECTIVES?

This sub-section states each individual research objective and determines whether the study met them.

1. *Identify temperature breaks in the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey.*

The data analysis (Chapter 4) successfully identified temperature spikes and temperature breaks throughout the initial stages of the export chain.

2. *Identify where temperature breaks occur during the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey.*

The data analysis (Chapter 4) successfully identified where temperature spikes / temperature breaks occur during each segment of the initial stages of the export chain. There were frequent temperature spikes / temperature breaks during the transportation segment, inspection segment of the cold storage stages and switchover to Steri during the cold storage stage.

3. *Identify the prominence of these temperature breaks (duration and severity)*

The data analysis (Chapter 4) successfully determined that there were temperature spikes / temperature breaks of varying severities and durations. During the degreening stage of Navels load two, the study recorded a maximum pulp temperature of 35.11°C and the surge lasted for approximately 10 hours. The highest recorded pulp temperature increase once the fruit had entered the cold chain was 7.28°C and the longest recorded temperature increase of 33 hours occurred during the Steri stage.

4. *Identify the causes of these temperature breaks.*

The interpretation chapter (Chapter 5) provides several causes for the temperature spikes / temperature breaks that occur during the initial stages of the export chain. The main causes are exposure to ambient temperatures and improper cold chain management.

5. *Determine whether they are avoidable or unavoidable temperature spikes / temperature breaks.*

The recommendations section (Section 6.2) identified temperature spikes / temperature breaks from both categories. The temperature surge during the degreening stage is an avoidable occurrence and should be eliminated. The temperature spikes during the transportation segment are unavoidable while using tautliner trailers and should be minimised. The temperature breaks and temperature spikes during the inspection segment and Steri switchover are unavoidable with the current available infrastructure and should be minimised. Temperature spikes during the Steri stage are avoidable and should be eliminated.

6. *Analyse the effect that temperature breaks have on citrus quality by reviewing the existing literature.*

The literature review (Chapter 2) summarises and explains the negative implications of temperature breaks for citrus quality. Temperature breaks accelerate fruit respiration and increases ethylene production, which leads to enhanced decay and a shorter shelf life. In addition, it can cause cosmetic deficiencies.

7. *Provide possible solutions to reduce unavoidable temperature breaks and, if possible, eliminate avoidable temperature breaks.*

The recommendations section (Section 6.2) provides at least one solution to each problem that the study identified.

6.1.3 DID THE STUDY ANSWER THE RESEARCH QUESTIONS?

This section states each individual research question and determines whether the study answered them successfully.

1. *Do temperature breaks occur along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?*

The data analysis (Chapter 4) identified temperature spikes / temperature breaks during each segment of the initial stages of the export chain and, therefore, answered this question successfully.

2. *Where do temperature breaks occur along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?*

The data analysis (Chapter 4) identified temperature spikes / temperature breaks during not only each stage, but also each segment of each stage and, therefore, answered this question successfully.

3. *What are the severity and duration of these temperature breaks?*

The data analysis (Chapter 4) determined temperature spikes / temperature breaks with varying severities and durations and, therefore, answered the question successfully.

4. *Why are temperature breaks occurring along the initial stages of the cold chain for Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey?*

The interpretation chapter (Chapter 5) identified several problem areas and possible causes to the breaks and, therefore, answered the question successfully.

5. *Are these temperature breaks avoidable or unavoidable?*

The recommendations section (Section 6.2) identified temperature breaks from both categories and, therefore, answered the question successfully.

6. *Do these temperature breaks have a negative impact on the quality of the citrus?*

The literature review (Chapter 2) concludes that temperature breaks can have debilitating effects on citrus quality and, therefore, answered the question successfully.

7. *How can the various role players in the export chain possibly eliminate or minimise these temperature breaks and their influence?*

The recommendations section (Section 6.2) supplies at least one recommendation to each problem and, therefore, answered the question successfully.

6.1.4 CONCLUSION

The study achieved its aim and purpose by completing its objectives and answering the research questions. It successfully makes possible recommendations to improve the problem areas that the interpretations identified.

6.2 RECOMMENDATIONS

6.2.1 INTRODUCTION

As mentioned in Section 2.11 of the literature review, Freiboth (2012) differentiates between two types of temperature breaks, namely avoidable temperature breaks and unavoidable temperature breaks. Section 2.11 explains the difference between the two types of temperature breaks. During this study, the researcher identified temperature breaks in both categories. The study identified six problems within the South African leg of the citrus export cold chain from Citrusdal to the USA. This section identifies whether the problems are avoidable or unavoidable and provides recommendations that may help the specific role players solve these problems. It is important to note that certain unavoidable temperature breaks may become avoidable as the cold chain changes and evolves.

6.2.2 RECOMMENDATIONS PER FINDING

6.2.2.1 FINDING ONE – TEMPERATURE SPIKE DURING DEGREENING

This problem is an avoidable temperature spike. Sections 5.2.2 and 5.3.1 mentioned that many industry experts criticise the degreening process, because it accelerates fruit respiration significantly.

Currently, however, citrus supply chains require the degreening process, because it helps producers meet customers' standards. When the peel is in its original (green) harvesting conditions, local retailers and especially the export market will reject the citrus. Therefore, the degreening process is a standard procedure and cannot be excluded.

Farms that administer the degreening process in their private capacity should invest in pulp and ambient temperature probes and not rely solely on the temperature readings provided by the control centre with which the temperature is set. The degreening process dictates the administering of gasses like Carbon Dioxide (CO_2) into the room that further influence the temperature of the fruit. These temperature changes may go undetected by the control centre. Temperature monitoring devices like the ones at Company K enables a more hands-on approach with the temperature of the fruit in the degreening room.

Furthermore, it may be useful to conduct further research on the effect that the degreening process has on the quality and shelf life of the citrus. This may help farmers and exporters to develop a degreening process that is safer to administer and does not lead to these temperature surges. Another possible point for consideration is the ethical aspect to the degreening process. For example, most consumers may not be aware that the fruit undergoes this procedure. From an ethics point of view, educating consumers about the procedure may help reduce the need for degreening and thereby increase the citrus' shelf life.

6.2.2.2 FINDING TWO – TEMPERATURE INCREASES DURING THE TRANSPORTATION SEGMENT OF THE PACKHOUSE/ TRANSPORTATION STAGE

Temperature increases during unrefrigerated transportation are unavoidable, but their influence can be minimised. There are two main causes for these temperature increases. Firstly, the day temperature increases as the day progresses from the morning to the afternoon. Secondly, the airflow inside tautliners is insufficient to keep the fruit cool. Therefore, a possible solution to minimise the effect of day temperatures on citrus' temperature is freight planning. Scheduling transportation in such a way that it occurs during cooler parts of the day might not necessarily prevent temperature spikes, but it can reduce their magnitude. Furthermore, it may help prevent temperature spikes from evolving into temperature breaks.

Fruit respiration inside tautliners contributes to the temperature increases caused by the time of day. Therefore, improving the airflow inside tautliners for citrus transportation allows hot air to be funnelled out of the trailer. It may also allow cooler air (generated by the truck's travelling speed) to enter the trailers from the front. This may further reduce the effect of temperature increases during the transportation segment. Another possible solution is switching to refrigerated transportation. This alternative is more expensive, but it is also the most effective, because it eliminates the effect of the sun and generates airflow through a power source.

6.2.2.3 FINDING THREE – TEMPERATURE BREAKS AND SPIKES DURING INSPECTION IN THE COLD STORAGE STAGE

Temperatures that increase during inspection can be classified as both avoidable and unavoidable, depending on the role player's capital capabilities. This study treats them as unavoidable. These spikes occur, because the citrus acclimatises to the temperatures inside the cold store. Upon their removal, the citrus quickly reacts to the outside temperatures, because they are significantly higher than the temperatures inside the cold store. As a result of these temperature differences, the citrus are especially prone to temperature breaks. Hence, this segment reported numerous irregularities throughout the temperature trials.

Conducting these inspections in more controllable environments may benefit fruit quality significantly. Ensuring that the inspection area is at least a shaded area may already reduce the effect of temperature increases. The ideal solution is that the inspection occurs in a temperature-controlled environment like an air-conditioned room. However, these solutions are capital intensive and require a proper trade-off analysis.

6.2.2.4 FINDING FOUR – TEMPERATURE BREAKS AND TEMPERATURE SPIKES DURING THE SWITCHOVER FROM COLD STORAGE TO STERI

Ambient temperatures influence the citrus' temperature when the pallets move from the cold stores to the Steri chambers. Section 5.3.4 explains that cold store temperatures are significantly lower than outside temperatures. In other words, without proper management, temperature breaks occur relatively quickly. During the study there were cases where they did not occur, which means that these are avoidable temperature breaks. However, the occurrence of temperature spikes in this segment, is unavoidable during hotter times of the day.

Therefore, temperature breaks during this segment are avoidable, but temperature spikes are unavoidable. Proper logistical planning and execution is the best possible solution to this problem. If the switchover process occurs efficiently, Company K can prevent temperature spikes from progressing to temperature breaks. In other words, Company K must make sure this switch takes a minimal amount of time and, thereby, limit the citrus' exposure to ambient temperatures.

6.2.2.5 FINDING FIVE – TEMPERATURE SPIKES DURING THE STERI PROTOCOL

Temperature spikes during the Steri protocol are avoidable temperature spikes. If they progress to temperature breaks, the temperature breaks are also avoidable. Mostly, temperature increases during this period result from poor cold chain management. Company K already utilise temperature probes inside the Steri chambers, but investing in more temperature probes, so that they can probe more citrus may improve their cold chain performance during the Steri protocol.

Company K should properly train new employees in understanding the effect of temperature on citrus. Furthermore, management needs to make cold chain stabilization a top priority during the Steri protocol and not treat it as a formality. This will improve SA's competitiveness in an increasingly competitive international market. The approach towards the Steri protocols should be a hands-on approach with continuous temperature monitoring.

6.2.2.6 FINDING SIX – TEMPERATURES FALLING BELOW THE CI THRESHOLD DURING THE STERI PROTOCOL

This problem stems from poor cold chain management and is avoidable. Fruit positioned close to an air vent are especially susceptible to CI. Some of the same recommendations from Section 6.2.2.5 apply to this section. These include increasing the number of temperature probes and proper training to understand the cold chain. Furthermore, when personnel set the temperatures on the control panel, it should be in such a way that CI never becomes a threat. It is best to steer clear of temperatures that exceed the CI threshold from the initiation of the protocol, instead of relying on judgement to cool the fruit down as quickly as possible.

6.2.3 CONCLUSION

This section identified solutions that are situation specific. However, they may serve as examples to other citrus/fruit supply chains as well. Such supply chains may be able to modify these solutions based on their situation and formulate similar solutions.

6.3 FUTURE WORK

6.3.1 INTRODUCTION

While undertaking this study, several other topics that may be worth investigating surfaced. This chapter identifies these topics and briefly explains what they entail.

6.3.2 IDEAS FOR FUTURE RESEARCH

6.3.2.1 IN-DEPTH INVESTIGATION OF ORCHARD ACTIVITIES

Farm A stated that investigating their orchard activities would significantly complicate the farms logistical processes, as a result of the fast-moving nature of their harvesting process. However, temperatures fluctuate significantly in the orchard. This fluctuation results directly from changes in day temperatures. Higher temperatures influence fruit respiration significantly and have negative implications on fruit quality (Cronjé, 2019). Therefore, conducting an in-depth investigation on citrus' temperature profile during orchard activities may be valuable to the industry.

6.3.2.2 IN-DEPTH INVESTIGATION OF DEGREENING PROCESS

The significant spike during Navels load two's degreening stage led to this recommendation. Many experts oppose the degreening procedure, because it shortens the citrus' shelf life (Cronjé, 2019). Determining the regularity of temperature spikes like this would provide further clarity about the exact impact that degreening has on citrus quality. Therefore, investigating the degreening process alone through analysing a significant number of consignments and cultivars on different farms may be a feasible topic for future research.

6.3.2.3 TEMPERATURE BREAKS DURING THE TRANSPORTATION SEGMENT AND THEIR MAGNITUDE

During all four consignments, temperature increases occurred during the transportation segment. If a future researcher investigates the magnitude of these temperature increases for a larger sample size, during different times of the year and in different positions inside the trailer, it would provide the industry with a better understanding of citrus' temperature profile during transportation. It may also assist producers from Citrusdal in formulating ideas that minimise the occurrence and impact of temperature increases during the transportation segment.

6.3.2.4 EFFECTIVENESS OF THE NEWLY PROPOSED REFRIGERATED TRANSPORT METHOD FROM SAFT KILLARNEY/ CFC TO THE QUAYSIDE

Company J conducted a trial run that entailed transporting the citrus from two nearby cold stores directly to the quayside, thereby, eliminating some of the middle-man activities carried out by Company K. Originally, this study was going to map the temperature profiles of these trial runs, which did not realise due to unforeseen circumstances. A future study that investigates the efficiency of this newly proposed method would enable researchers to draw interesting comparisons with the current conventional method.

6.3.3 CONCLUSION

The fact that the researcher managed to identify ideas for future research from the study contributes to the feasibility of the study. The four recommended topics in Section 6.3 may contribute to current knowledge about the industry and help SA to improve its competitiveness in the global market.

6.4 VALUE TO THE INDUSTRY

6.4.1 INTRODUCTION

This final section identifies how this research is valuable to the industry.

6.4.2 VALUE

The temperature trials conducted during this research managed to identify the occurrence, location, frequency and severity of temperature breaks and temperature spikes in the initial stages of the export cold chain of Clementines and Navels Oranges from Citrusdal to the Port of Newark, New Jersey. Furthermore, the study was able to provide possible solutions to the problems, that may increase the quality and prolong the shelf life of citrus produced in the Citrusdal region. This information is valuable for the SA citrus industry and can help improve its competitiveness.

The Citrusdal region is one of South Africa's main citrus producing regions and plays an important role in the SA fruit industry. It exports a significant amount of produce each year and is one of the only regions in SA that can export citrus to the USA, because it is black spot free. The SA citrus industry can protect this unique region by considering this research and making a conscious effort to eliminate avoidable temperature breaks and minimise unavoidable temperature breaks.

6.4.3 CONCLUSION

This research identified problems and possible solutions that are valuable for the SA fruit and citrus industries. It identified various problems within the export cold chain of Clementines and Navel oranges from Citrusdal to the Port of Newark, New Jersey. By considering the recommended solutions, the SA citrus industry can increase its international competitiveness.

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