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Research article

A comparison of different technologies to improve temperature control in refrigerated containers: A table grape export case

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ABSTRACT

Purpose: Table grapes are exported in refrigerated (reefer) containers owing to their temperature sensitivity. Previous studies have found that insufficient airflow around pallets of fruit cause hotspots in reefer containers, which could negatively affect fruit quality. This study compared the efficacy of two technologies fitted inside reefer containers to improve airflow for table grape shipments.

Method: Ambient and pulp temperature sensors were inserted in two shipments of three containers each; each shipment had one container fitted with airflow Technology 1, one fitted with airflow Technology 2, and a control container. Sensors were placed in cartons in the top, middle and bottom layers of six pallets per container to obtain the ambient and pulp temperature profiles of table grapes along the export cold chain from the cold store in South Africa until the destination distribution centre in the Netherlands. Descriptive statistics and two-way ANOVA tests were used to analyse the datasets.

Findings: The largest number of temperature breaks and the longest temperature breaks were recorded in the control containers. Overall, the containers fitted with airflow technologies fared better than the control containers. The containers fitted with Technology 2 performed marginally better than those fitted with Technology 1. However, the sample size of this study was too small to draw definitive conclusions. Further research with larger sample sizes is required for more definitive results.

Originality: This article identifies areas along the table grape export cold chain where temperature deviations occur more frequently and links the temperature deviations to product quality. It also ascertains which airflow technologies can help to limit the deterioration of product quality and cut financial losses.

1. Introduction

South Africa was the fourth largest (in terms of volume) and the sixth largest (in terms of value) table grape exporting country globally in 2021, exporting 368 366 tonnes (8%) of the global export value [1]. Although table grapes are exported to many countries from South Africa, the majority is exported to Europe (approximately 50%) and the United Kingdom (approximately 25%) [2]. The rest are shipped to other markets, including India, the USA and Canada [3].

Table grapes are extremely temperature sensitive. During export, the fruit is transported over long distances from a hot climate,

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where average maximum daytime temperatures during January and February range from 32 °C to 39 °C in the production regions [4]. Proper temperature management along the table grape export cold chain is therefore crucial for maintaining fruit quality.

Table grapes are exported in refrigerated (reefer) containers. Previous studies have found that insufficient airflow in reefer containers causes hotspots [5,6]. This has led to the development of technologies to improve the airflow through and around pallets of fruit in reefer containers [6–8]. Company X, a large table grape exporter from South Africa, requested a study to compare the efficacy of two of these technologies for table grape shipments from South Africa to the Netherlands. One technology (Otflow) covers part of the container floor to improve the airflow, while the other technology (RAFT) changes the direction of the airflow through the pallets of fruit from vertical to horizontal. In past years, Company X has experienced an increase in claims because of poor quality table grapes reaching the customer, resulting in financial losses.

The main purpose of this research was to identify to what extent airflow Technology 1 and airflow Technology 2 can reduce the occurrence of hotspots in reefer containers. Live temperature trials were conducted by using three containers on two vessels, the Paris and the Maira. On each vessel, one container was fitted with airflow Technology 1 and one with airflow Technology 2. The third container was the control container. All the containers were fitted with temperature sensors. Hotspots were identified by comparing the temperature profiles of containers fitted with the two technologies with each other and with that of a control container to see whether any patterns, similarities or differences emerged. The study also attempted to link any deviations from protocol temperature along the cold chain to quality issues with table grapes.

While previous studies have been conducted to compare each technology individually with a control container, no published studies are available that compare the two technologies with each other and a control container. The conclusions of these studies were based on temperature measurements and in one case also humidity measurements [9,10]. The research study endeavoured to answer the following research questions: (1) What do the temperature profiles look like for the containers containing Technology 1 and Technology 2, and for the control containers? (2) Where and how often do temperature breaks occur along the table grape export supply chain from South Africa to the Netherlands? (3) How long do temperature breaks last? (4) If temperature breaks were present, did containers with more breaks result in worse quality reports than those with fewer breaks? (5) Did the use of airflow Technology 1 and airflow Technology 2 deliver better quality table grapes at the export destination?

2. Materials and methods

2.1. Materials

The materials used in this study consisted of six reefer containers each filled with 20 pallets of table grapes provide by Company X and a selection of temperature sensors to measure ambient and fruit pulp temperature as explained below. In addition, Otflow floor coverings and RAFT airflow kits were fitted in two containers each.

2.2. Methods

A deductive approach was used for the study. Prior studies on the table grape cold chain and other relevant literature were examined before data collection commenced. A mixed-method approach was used as both qualitative and quantitative data were gathered. This is a cross-sectional study, as the research took place at a specific point in time [11].

Primary qualitative data was gathered through observations at the cold store where temperature sensors were placed in the pallets of table grapes, and on loading days to supervise pallets being placed in the reefer containers in the correct locations and orientations. In addition, industry experts with at least 10 years' experience in the industry were identified and interviewed by the researchers to obtain an understanding of the table grape export cold chain.

Quality reports were examined as secondary qualitative data to establish the relationship between deviations from protocol temperature and product quality.

Primary quantitative data comprised the ambient and pulp temperature profiles of table grapes along the export cold chain from the cold store in South Africa to the destination distribution centre in the Netherlands.

2.2.1. Placement of sensors

Sensors were inserted into two shipments of three containers each; each shipment had one container fitted with airflow Technology

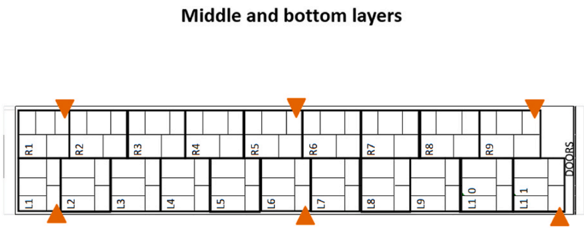

Fig. 1. Sensor positions in bottom and middle layers of pallets.
Source: Compiled by the authors for this research study.

1, one fitted with airflow Technology 2, and a control container.

Sensors were placed in cartons in the top, middle and bottom layers of six pallets per container. Older Sensitech TempTale radio frequency (RF) sensors were used to measure ambient temperature in the bottom and middle layers of the pallets (Fig. 1). New Sensitech TempTale RF sensors and new CL Circular ambient sensors were inserted in the top layer (Fig. 2). In addition, grape berries were skewered on three probe sensors to measure fruit pulp temperature. The probe sensors were inserted in locations identified in the literature as the hottest and coldest areas in the container (Fig. 2) [6,12]. Each container was thus fitted with 18 ambient and 3 fruit pulp temperature sensors. The accuracy of the sensors is ±0.55 °C from −18 °C to +50 °C.

The choice of sensors was largely determined by the availability of funds and donated sensors. The older Sensitech TempTale RF sensors were donated by Sensitech in South Africa. The new Sensitech sensors were bought by Company X and the CL Circular sensors donated by Company Y.

Sensors were switched on just prior to placement in the boxes of produce. The locations of the sensors were indicated with white ribbons attached to the sensors, neon yellow stickers on the layers of cartons containing sensors and neon green stickers holding the ribbons in place at the exact locations of the sensors (Fig. 3). A sticker reading 'Wall' was also stuck onto the side of the pallet containing the sensors and which needed to be placed against the container wall during loading.

2.2.2. Fitment of Otflow floor covering

Two containers were fitted with the funnel-shaped Otflow floor covering. For ease of installation, Otflow comprises nine trapezoid-shaped pieces, each big enough to accommodate two pallets. The first piece, the broadest, is placed on the floor at the back of the container. Two pallets are loaded before the next narrower sheet is placed on the floor, slightly overlapping the previous one. This process continues until all nine sheets have been placed along the container floor and all 20 pallets have been loaded. This is a relatively simple process that does not add significantly to the loading time, once the personnel is acquainted with Otflow.

2.2.3. Fitment of reefer airflow technology kit

Two containers were fitted with the Reefer Airflow Technology (RAFT) kit. The T-bar floor of the reefer is covered with a plastic sheet from the back of the container to about 3 m from the doors of the container. This sheet folds up in such a way that it covers 10 cm of the container walls. Two Styrofoam bars are attached to the back wall of the container. Once pallets R3 and L4 have been loaded, cardboard panels are placed around the bottom of the pallets to cover the gaps beneath them to stop airflow and a collapsible carton panel is placed across the top of the pallets to prevent air flowing over the pallets. This is repeated after pallets R6 and L7 have been loaded. After pallets R7 and L8 have been loaded the last set of cardboard panels are placed around their bases and the last set of collapsible carton panels are fitted on top of pallets R9 and L11as shown in Fig. 6.

2.3. Constructs and variables

Temperature and reefer airflow technologies are the primary constructs in this research study. The technology is measured in terms of the value that it is claimed to add to the cold chain of table grapes. The secondary constructs are quality and time. Fruit quality is a

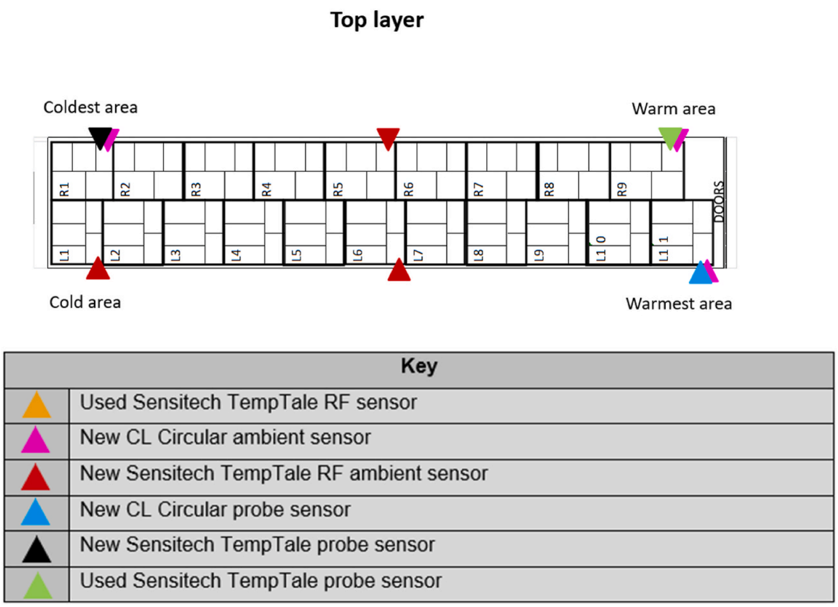

Fig. 2. Sensor positions in the top layer of pallets.
Source: Compiled by the authors for this research study.

Fig. 3. Neon yellow and neon green stickers showing the locations of sensors in the pallets.

measure of the success of the supply chain, and the appearance, texture and taste of the table grapes give an indication of the product quality. Time provides more information about the duration of the export cold chain.

2.4. Data analysis approach

After the sensors had been retrieved from the containers at the arrival warehouse, the data was captured from each sensor and then merged into a single Excel spreadsheet. As the actual time at which the sensors were retrieved at the arrival warehouse was unavailable, the temperature data readings were terminated at the point when there was a sudden significant increase in temperature at the arrival warehouse. This was deemed to be an indication that the sensors had been removed from the pallets.

Descriptive statistics and visualisation were completed using this data sheet, set up in a way that highlighted the five main stages of the table grape export cold chain, namely 'Cold store', 'Origin port', 'Sea route', 'Destination port' and 'Arrival warehouse'. STATISTICA 14, Data Science Workbench version 14 was used to analyse the data captured on the Excel sheet. Tableau was used for visualisation and to make comparisons between various variables.

In addition, two-way ANOVA tests were used to determine whether there were significant differences between the temperatures recorded for the two airflow technologies and the control container in the (1) various sensor locations and (2) various pallet locations.

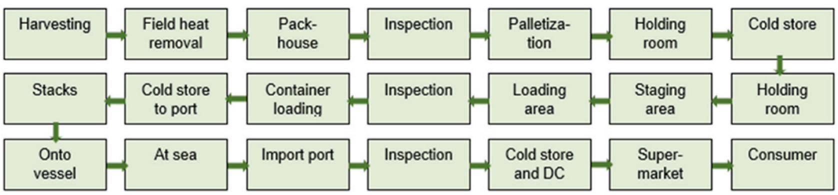

Fig. 4. Generic table grape export supply chain.
Source: Adapted by the authors from [16].

3. Bibliographic review

3.1. Table grape cold chain

A typical table grape export supply chain starts with harvesting on a farm in the country of origin and ends with the consumer in the destination country (Fig. 4). After harvesting, the grapes are transported to a cold room at the packhouse for the removal of excess field heat and then packed into cartons. After inspection, the cartons are palletised and placed in another cold room until the pallets can be transported to the cold store. At the cold store, the pallets are force-air cooled until the fruit pulp temperature is −0.5 °C, which is the ideal storage and transport temperature for table grapes [13–15]. This temperature should be retained for the duration of the cold chain.

According to the Perishable Products Export Control Board (PPECB) a cold chain can be described as the ‘seamless movement of fresh, chilled or frozen products, from the production area to the market, through various storage and transport mediums, with no change in optimum storage temperature and relative humidity’ [17].

3.2. Table grapes and temperature

Table grapes are exceptionally sensitive to temperature and special care is needed during storage and transportation to ensure that the highest possible quality of fruit reaches the consumer [18]. Therefore, temperature should be carefully managed across all stages of the cold chain to ensure that deviations from protocol temperature are minimised. Adhering to the protocol temperature of −0.5 °C for table grapes will cause a low rate of respiration and moisture loss, which will prolong the fruit’s shelf life and marketability [13–15].

As it is not practical to maintain the temperature at exactly −0.5 °C throughout the entire cold chain, deviations between −1.5 °C and 2 °C are acceptable. An agreement was reached within the industry that a temperature break (unacceptable deviation) can be defined as any increase in temperature higher than 2 °C or any decrease below −1.5 °C for longer than 90 min [18–20]. Important to note is that many small temperature breaks can have the same detrimental effect on the fruit as a few larger ones [18](Freiboth et al., 2013).

Although temperature is the most important factor when considering the quality of table grapes, other temperature-related factors also affect fruit quality, such as the respiration rate of the fruit, moisture loss, humidity and relative humidity [13].

3.3. Reefer containers and airflow technologies in the table grape industry

A refrigerated container (reefer) is a container with its own refrigeration unit. These units can be plugged into electric power supplies at depots, terminals and on board vessels. During road or rail transport, diesel-powered generators (gensets) are required [21].

The floor of a reefer container is referred to as a ‘T-bar’ floor and allows air to move underneath the cargo being transported [12]. From the refrigeration unit at the back of the container, cold air is blown through the vents near the floor of the reefer, allowing the cold air to move through and around the pallets to the container doors. As the air circulates through the fruit, it removes the respiratory heat. The warm air assembles near the roof of the container, from where it flows back to the refrigeration unit. The ‘warmed’ air is cooled within the refrigeration unit. This process repeats itself throughout the journey [22].

Temperature at set points can be maintained between −30 °C and 30 °C in a reefer container. It is, however, important to note that the key role of a reefer container is to maintain a set temperature; it cannot reduce the temperature of the load to the desired point [12]. Table grape exporters, therefore, precool their produce to the required protocol temperature before it is loaded into a reefer.

Proper loading is vital to avoid short-circuiting of the airflow and to ensure that the entire reefer floor is covered. Often uneven temperatures and deteriorating products are detected in reefer containers travelling over long distances because of the short-circuiting of cold air through the pallets of produce [8]. When pallets and cartons are not stacked effectively, respiratory heat cannot be removed, because air follows the path of least resistance. Inefficient loading can also result in the formation of hotspots throughout the container when airflow is restricted from moving through certain parts of the reefer. The T-bar floor must be covered entirely with pallets of produce to ensure that temperature-controlled air is effectively distributed throughout the container [21].

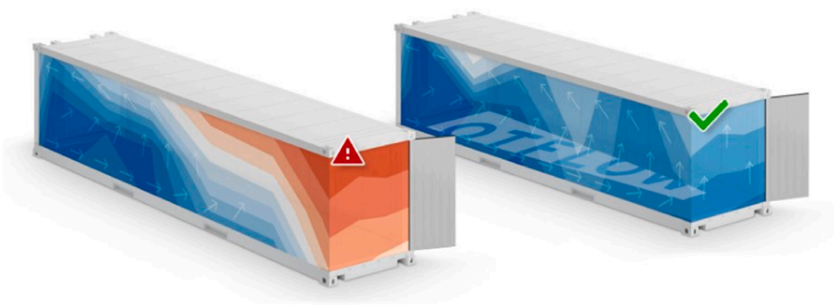

Fig. 5. Airflow within a reefer container without and with Otflow technology.
Source: [6].

Ref. [23] found that the vertical air flow through the pallets on the right hand side of the container was better than that on the left hand side, probably due to the difference in orientation of the pallets and the accompanying distribution of ventilation holes in the cartons. They found that the air flow made an undesirable short-circuit through the gap between the pallets on the left and right hand sides, resulting in low airflow near the doors. Ref. [24] showed that the design of the carton has a significant impact on the airflow in the reefer and its ability to remove the respiratory heat from the fruit. Ref. [25] compared the performance of different types of packaging for table grapes and found that 5 kg cartons with clamshell punnets (used in this study) had the best cooling rates, but also the most moisture loss.

3.3.1. *Otflow technology*

Otflow is a funnel-shaped floor covering, which covers a part of the floor of a reefer container in order to improve the airflow within the container. A trial was conducted with table grapes from South Africa to the Netherlands [10]. Three reefer containers were fitted with Otflow floor covering and compared with three control containers shipped on the same vessel. The results showed that the standard deviations around the mean values were lower in the containers fitted with the floor coverings than in the control containers. The average difference between the warmest and coldest temperatures was approximately 30% lower in the containers fitted with the floor covering than the control containers. Fig. 5 illustrates the airflow in a container without (left) and with Otflow technology (right). The container without the Otflow floor cover shows the formation of hotspots, especially at the top and close to the doors of the container. In the container fitted with an Otflow floor cover, cool air is circulated effectively throughout the container and temperatures are evenly dispersed to all corners. This improved airflow minimises product waste and contributes to better product quality [6].

3.3.2. *Reefer airflow technology*

Reefer Airflow Technology (RAFT) changes the direction of airflow inside a reefer container from vertical to horizontal. Cold air is forced to move from the refrigeration unit under a plastic sheet that covers the T-bar floor until approximately 3 m from the container doors. From here, air moves through the pallets containing fresh produce, in a horizontal direction as illustrated in Fig. 6. Cool air flows through a smaller space, excluding the top of the container. The laws of physics state that air velocity increases as it moves through the pallets in the direction of return air, and temperatures are therefore more evenly dispersed throughout the container [7].

Ref. [9] conducted trials with apples and citrus fruit to determine the impact on fruit pulp temperature, storage air relative humidity and fruit quality. Compared with a standard reefer container, the fruit pulp temperatures remained closer to the optimum temperature and the relative humidity could be maintained at more than 90%, resulting in better fruit quality.

3.4. *Quality control along the table grape cold chain*

Fruit colour/appearance, texture, flavour and nutritional value are four elements by which fruit quality is measured [27,28]. Quality, as defined by Kramer (1965), is 'the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit to the user' [27].

Temperature is the crucial factor that can have a significant effect on the quality of fruit, especially table grapes, which are extremely temperature sensitive. Although many factors influence the quality of table grapes, such as relative humidity, respiration rate and microbial growth, these factors are accelerated by fluctuations in temperature. The ripening rate of fruit directly influences its lifespan, which affects the ability of the fruit to sell and, therefore, to be profitable to a business.

The quality of fruit can be preserved through proper temperature management practices. Table grapes are categorised into three classes at harvesting: 'Extra Class', which are table grapes of superior quality; 'Class 1', which are of a high standard but lower than the previous class; and 'Class 2' [29]. The class determines to which markets and the price at which the table grapes will be sold. Extra Class and Class 1, for example, are exported, whereas Class 2 is sold to the local market. High quality standards provide the opportunity

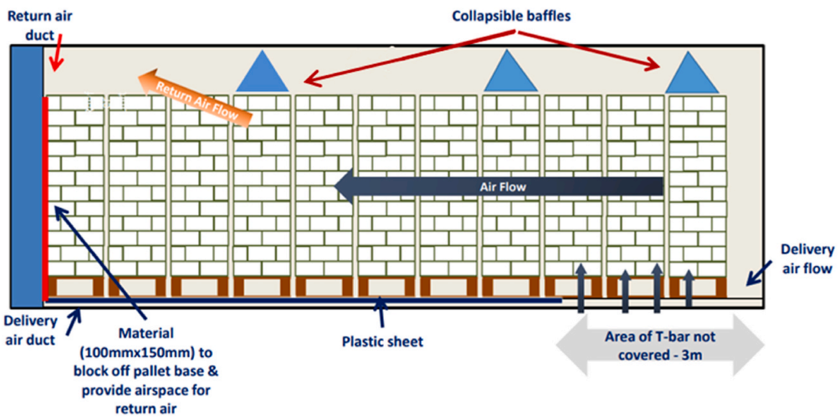

Fig. 6. Airflow in a reefer container with the RAFT kit.
Source [26].

to sell fruit to international markets, where premium prices will be paid.

3.5. Contribution

Although previous studies have identified areas along the table grape export cold chain that experience temperature deviations [16,18,19], this is the first study to link temperature deviations to product quality. In addition, this study also determines which airflow technologies can be used inside reefer containers to help limit a reduction in product quality. This will enable table grape exporters to reduce financial losses.

4. Results

This section discusses the comparison of the frequency and duration of temperature breaks along the five stages of the table grape export cold chain for the two airflow technologies and the control container, as well as the impact of these breaks on the quality of the

Table 1
Challenges along the table grape export cold chain identified by interviewees.

Location	Challenge	Frequency
Harvesting	- Strikes (e.g. disruptions)	1
	- Weather (hail, higher rainfall, insufficient rainfall, mould; can lead to unacceptable sugar levels; cannot harvest during rain)	7
	- Field heat not removed fast enough, therefore fruit to go to cold store as soon as possible	1
Packhouse	- Lack of precooling	1
Cold store	- Hotspots	1
	- Capacity issues (e.g. large intake volumes; cannot load out fruit as Port of Cape Town is closed; vessels bypass port due to weather conditions)	2
	- Labour behaviour (e.g. incorrect installation of technologies, unsatisfactory pallet positioning during container loading)	5
	- Loading of container (e.g. incorrect loading can lead to condensation; important to note that warmest area of container is at the doors)	2
Container	- Container shortages	2
	- Container equipment shortages	1
	- Lack of precooling	1
	- Designed for boxes, not pallets (hotspots form)	1
Transport	- Increased road transit times in South Africa and queueing to offload at port	1
	- No genset (leads to warmer temperatures within containers; important to note that no gensets are used when distances from cold store to port are short)	3
	- Claims (e.g. 43% claims due to bad quality table grapes)	1
	- Condensation impact	1
	- Strikes (e.g. taxi protests leading to disruptions)	1
	- Railway inefficiencies (e.g. lack of infrastructure due to cable theft, unreliability)	1
Port of Cape Town	- Delays	3
	- Strikes (i.e. delays)	1
	- Systems errors/offline (i.e. delays)	1
	- Truck booking systems	1
	- Capacity issues (e.g. shortage of equipment; volumes that exceed handling capacity)	1
	- Congestion (e.g. cold store capacity issues, delays)	4
	- Container terminal inefficiencies (e.g. delayed plug-in, labour behaviour, lack of transparency and operational tracking)	5
	- Insufficient equipment (e.g. to load during bad weather)	4
	- Labour behaviour (e.g. delayed plug-in and switch-on; lunchtime or shift change; unsatisfactory pallet positioning during container loading)	4
	- Container loading (e.g. no genset)	1
	- Poor planning (causes shortage of equipment)	1
	- Ships bypass Port of Cape Town (so cold stores run out of capacity)	1
	- Weather (e.g. mist and wind causing ships to bypass port or delays)	8
	- Container-loading guides not for sale (e.g. plastic guides currently used by one customer)	1
	- Spare labour (i.e. capacity issues)	1
	- Unqualified/inexperienced staff (i.e. impact on output)	1
	- Tedious paperwork at various gates causing delays and rising temperatures (especially when truck is without a genset)	1
	- Long equipment repair lead times	1
Sea route	- Container placement on vessel (e.g. container doors face the sun directly)	2
	- Outer layer of stacked containers on vessel gets warmer (e.g. exposed to the sun and warmer temperatures, especially when crossing the equator)	1
	- Ships bypass Port of Cape Town (e.g. port may be closed owing to strong wind)	1
	- Vessel power outages (i.e. warmer temperatures)	1
	- Delays (e.g. underwater currents)	1
Other	- Miscommunication (e.g. between shipping line, transporter and cold store)	1
	- Land-side loadshedding (power outages)	2
	- Long temperature protocol requirements to control pests for special markets (i.e. time consuming)	1
	- Poorly designed packaging (i.e. no proper cooling and poor quality fruit)	1
	- Increased production from other countries decreasing price of fruit because of oversupply	1
Total		**86**

table grapes sold to the end-consumer.

4.1. Interviews

Table 1 summarises various challenges that table grape exporters face in each cold-chain stage as identified by the interviewees. “Location” indicates the stage or location where the challenges arose. This was not limited to the five cold-chain stages used in this research, but included, for example, stages before the cold store (harvesting and packhouse), and the container itself, which is relevant throughout all stages of the cold chain.

4.2. Temperature profiles

Figs. 7 and 8 illustrate the temperature profiles along the entire table grape export cold chain for each airflow technology and each shipment from South Africa to the Netherlands. The lines reflect the median temperatures recorded by the bottom, middle and top sensors. Reference lines show the various stages along the cold chain and the allowed temperature range of between −1.5 °C and 2 °C.

Overall, the bottom sensors registered the coolest and the top sensors the warmest temperatures. Similar temperature spikes were seen in shipments as soon as the stages changed from cold store to origin port, which corresponds to the loading of the pallets into the containers. More temperature fluctuations are also seen during the cold store and origin port stages, with more consistent temperatures along the sea route.

4.3. Descriptive statistics

To describe the variables used in this research, summary statistics were used. Medians were used as the measure of central location for ordinal and continuous responses. For indicators of spread, standard deviations and quartiles were used.

The temperature ranges for the sensors placed in the bottom, middle and top layer of the pallets for each container on each of the two vessels travelling from the cold store in South Africa to the arrival warehouse in the Netherlands are captured in Figs. 9 and 10. Across all containers and sensor positions, more condensed interquartile ranges are visible during the origin port, sea route and destination port stages, indicating less temperature fluctuation. The opposite is true during the cold store and arrival warehouse stages, where interquartile ranges are wider. Wider ranges are also found for the sensors placed in the top layer of the pallets. The most significant occurrence is the wide interquartile range for the containers fitted with airflow Technology 1 at the arrival warehouse, where temperatures of higher than 20 °C were experienced. Temperatures were only considered up to a certain time in the arrival warehouse because the specific time that the sensors were removed from the pallets was not available.

Many outliers can be seen for both vessels and throughout all stages of the cold chain. Most outliers are present in the cold store and origin port stages. No temperatures below the lower limit of −1.5 °C were recorded.

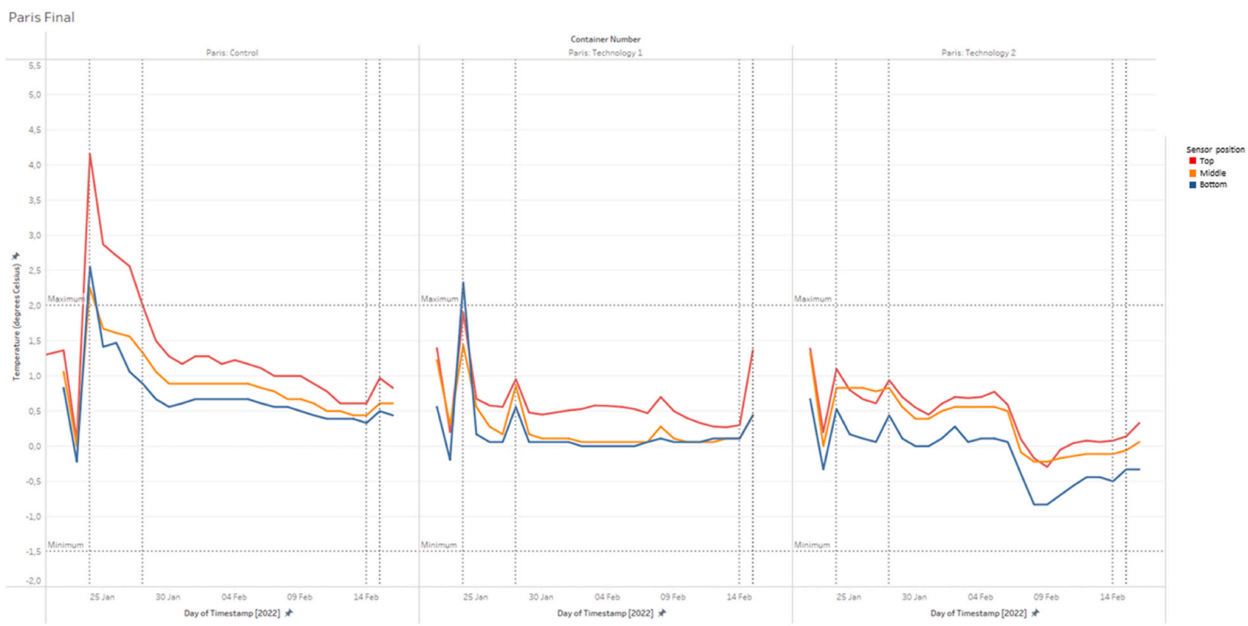

Fig. 7. Temperature profile along the export cold chain for the three containers on the Paris.

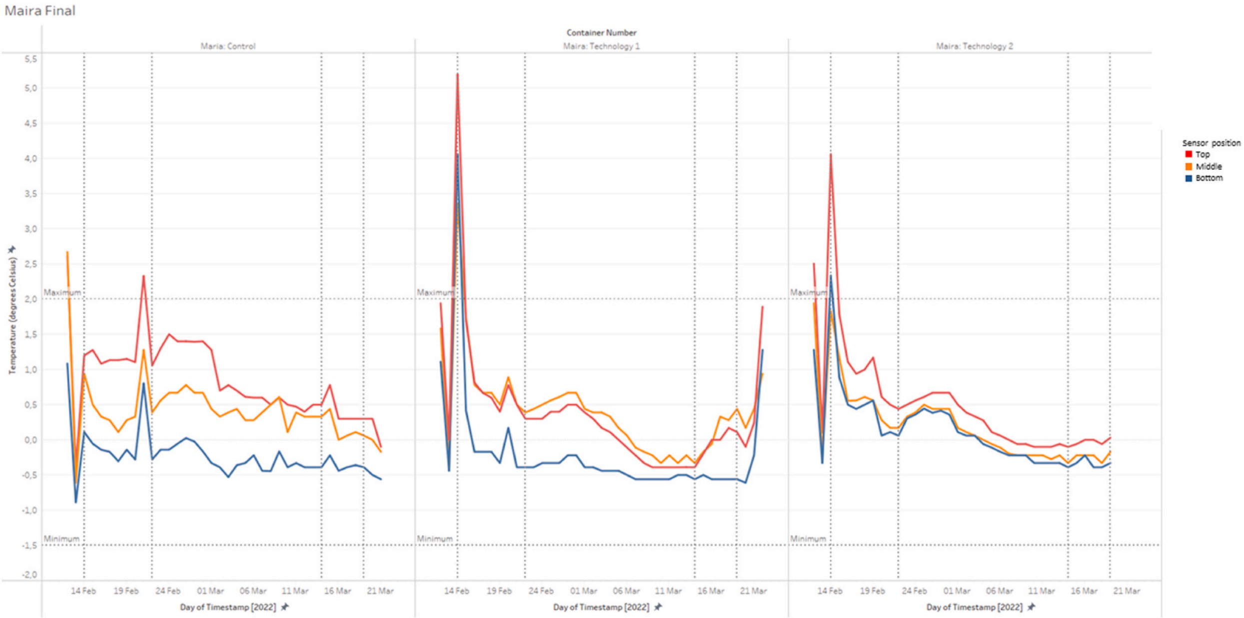

Fig. 8. Temperature profile along the export cold chain for the three containers on the Maira.

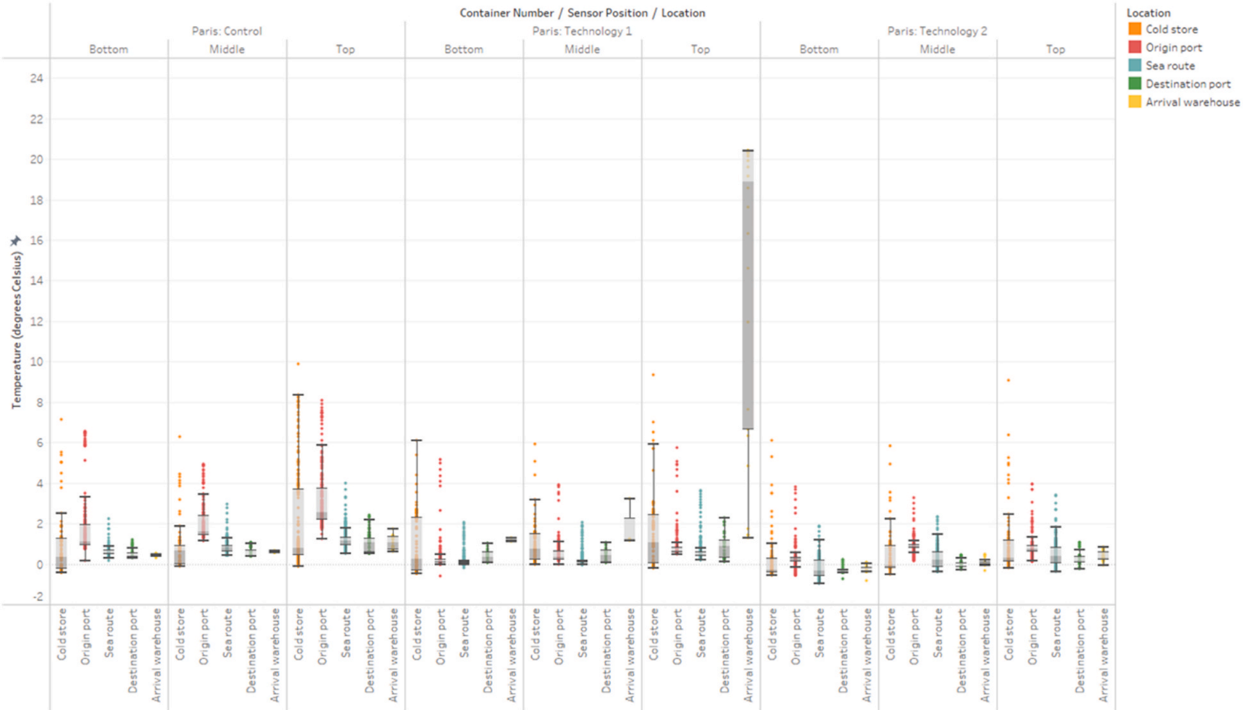

Fig. 9. Box and whisker plot per container on the Paris, per stage, per sensor position.

4.4. Two-way ANOVA tests

During ANOVA testing, one or more null hypotheses are tested. The probability of incorrectly rejecting the null hypothesis (H_0) when it is actually true, is referred to as the level of significance (alpha). For this study, an α-value of 5% was used. The null hypothesis is rejected when the *p*-value is less than 0.05, and the evidence suffices to support the alternative hypothesis (H_a) [30]. A *p*-value of $p < 0.05$, thus, represents statistical significance in hypothesis testing. Ninety-five per cent confidence intervals were used for the

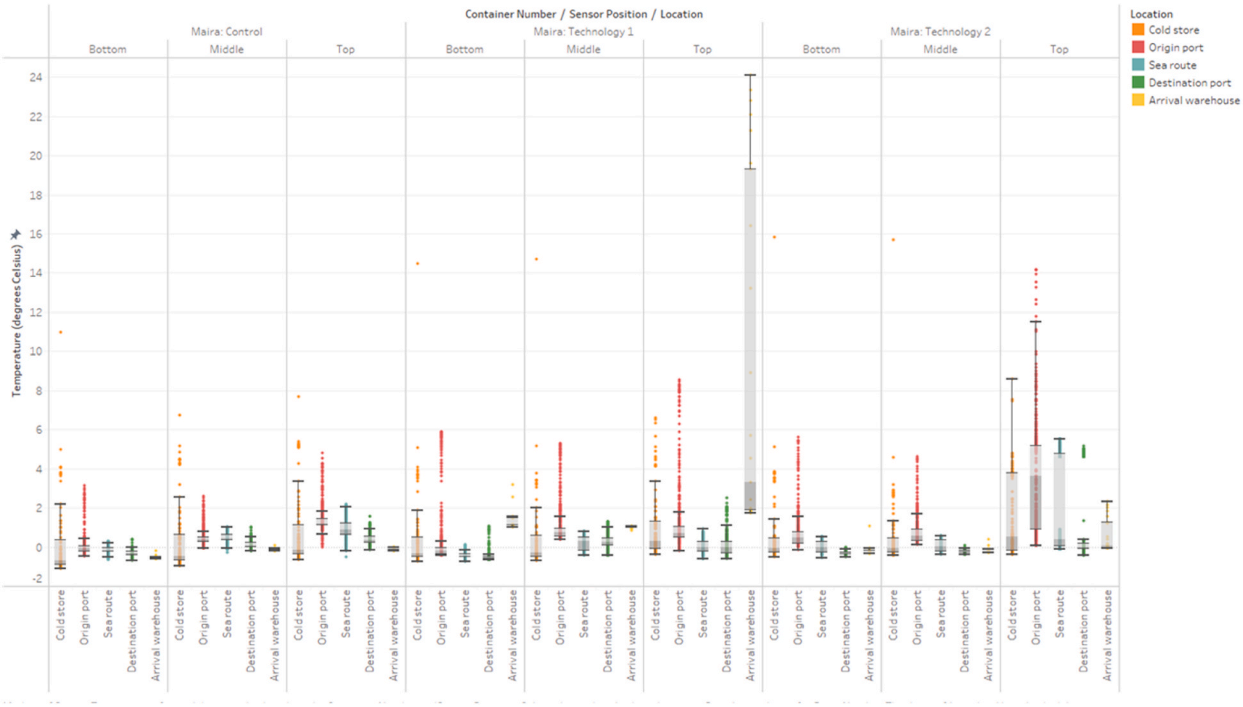

Fig. 10. Box and whisker plot per container on the Maira, per stage, per sensor position.

estimation of unknown parameters. Here, according to Ref. [30], a 95% probability exists that the results drawn from the sample apply to the general population.

The interaction between variables needs to be interpreted as soon as the two-way interaction is significant. The primary effects, however, do not need to be interpreted individually.

Two two-way ANOVA tests were conducted. The data provided per pallet position and per sensor position is the average temperature of containers containing the same technology on both vessels for each point in time over the entire cold chain. The graphs illustrate the average temperature per product (technology) in the specific container. The first ANOVA test was completed to isolate the

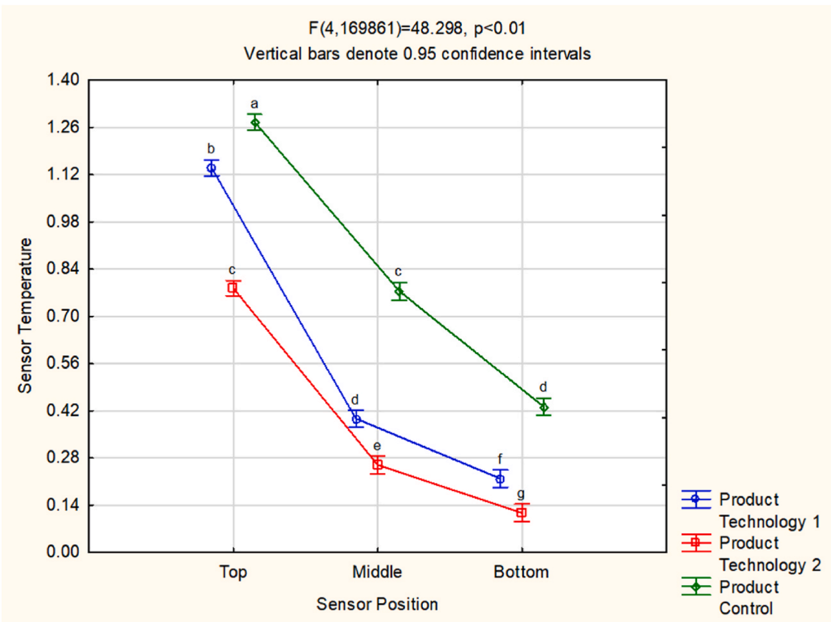

Fig. 11. Sensor position vs product least square means graph along all stages of the cold chain.

sensor position (bottom, middle and top level of pallet) and product variables (Technology 1, Technology 2 and control). The aim of the second ANOVA test was to isolate the pallet position (closed end, middle and door end of container) and product variables (Technology 1, Technology 2 and control). Two hypotheses are applicable:

Hypothesis 1. H_0: There is no interaction between the sensor position and the product within a reefer container.
H_a: There is an interaction between the sensor position and the product within a reefer container.

Hypothesis 2. H_0: There is no interaction between the pallet position and the product within a reefer container.
H_a: There is an interaction between the pallet position and the product within a reefer container.

4.4.1. *Overall findings for Hypothesis 1*

Hypothesis 1 was first tested for the entire cold chain and subsequently for each stage. In the first case, the interaction between the sensor position and the product (Sensor Position*Product) along the export cold chain of table grapes is significant, as indicated by the F-value = 48.3 and p-value <0.01. Therefore, the null hypothesis is rejected in favour of the alternative hypothesis. As seen in Fig. 11, the mean (average) temperatures for all three sensors positions over the entire cold chain are the highest for the control containers and the lowest for Technology 2.

The least significant difference test was used to determine which of the group means differ significantly from one another. There is a significant difference between the means when the lettering for any two means is completely different, such as ‘a’ and ‘b’. The means do not differ significantly when the lettering contains one or more common letters, such as ‘c’ and ‘c’.

In Fig. 11, the temperatures experienced by the top sensors of the control container, as well as the containers fitted with Technology 1 and Technology 2, differ significantly because the letters associated with the three sensor positions are different (a, b and c). This pattern is the same for the middle sensors of the three containers (c, d and e) and the bottom sensors (d, f and g).

The top sensors of the container equipped with Technology 2 and the middle sensors of the control container do not differ significantly, as shown by the letter ‘c’ that is associated with both positions. This is the same for the middle sensors in the container fitted with Technology 1 and the bottom sensors of the control container, both associated with letter ‘d’.

Table 2 summarises the average ambient temperature per cold chain stage and sensor position for both similar (same technology) containers on both vessels. The ‘overall’ stage corresponds to the analysis above for the entire cold chain. In each row the warmest temperature is indicated in red and the coolest in green.

When analysed per stage, the average temperatures during the cold store stage (which includes loading the containers) were the highest for Technology 1 and the lowest for Technology 2. In the origin port, the control container recorded the highest average temperatures, whereas the top sensor in Technology 1 and the middle and bottom sensors in Technology 2 recorded the lowest average temperatures. For the sea route, the control container also recorded the highest average temperatures, whereas the top and middle sensors in Technology 1 and the bottom sensors in Technology 2 recorded the lowest average temperatures. In the destination port, the top and bottom sensors in the control container and the middle sensor in Technology 1 recorded the highest temperatures, whereas the top and bottom sensors in Technology 1 and the middle sensor in Technology 2 recorded the lowest temperatures. For the arrival warehouse, all the sensors in Technology 1 recorded the highest temperatures, whereas the sensors in Technology 2 recorded the

Table 2
Summary of the average temperatures (°C) per sensor position for each of the similar (same technology) containers on both vessels.

Stage	Sensor position	Control	Technology 1	Technology 2
Overall	Top	1.27	1.14	0.78
	Middle	0.77	0.40	0.26
	Bottom	0.43	0.22	0.12
Cold store	Top	1.12	1.32	1.00
	Middle	0.84	0.96	0.67
	Bottom	0.55	0.75	0.40
Origin port	Top	1.98	1.09	1.55
	Middle	1.13	1.07	0.82
	Bottom	0.86	0.70	0.69
Sea route	Top	1.24	0.26	0.47
	Middle	0.77	0.16	0.19
	Bottom	0.42	0.12	-0.02
Destination port	Top	0.50	0.23	0.35
	Middle	0.26	0.30	-0.19
	Bottom	-0.18	-0.29	-0.27
Arrival warehouse	Top	0.54	11.52	0.35
	Middle	0.19	1.25	-0.04
	Bottom	0.09	1.24	-0.17

lowest temperatures.

4.4.2. Overall findings for Hypothesis 2

Hypothesis 2 was first tested for the entire cold chain and subsequently for each stage. In the first case, the interaction between the pallet position and the product (Pallet Position*Product) along the export cold chain of table grapes is significant, as indicated by the F-value = 534.83 and p-value <0.01. Therefore, the null hypothesis is rejected in favour of the alternative hypothesis.

The least significant difference test was used to determine which of the group means differ significantly from one another. For this ANOVA test, the letter combination 'RR' was used to indicate the pallets stacked along the right-hand side of the containers. Statistica reads an 'R' as a rand value, therefore a second 'R' was added. The letter 'L' was used to indicate the pallets stacked along the left-hand side of the containers (see Fig. 1).

Fig. 12 shows that temperatures recorded by the sensors in pallet positions L1 and L6, and RR1 and RR5 were similar compared to positions L11 and RR9, which experienced temperature spikes. The right-hand side of the container seemed marginally to significantly cooler than the left-hand side, except for the control container that had a hotspot at pallet position RR9, on the right-hand side close to the doors. Technology 1 had a hotspot at pallet position L11, on the left-hand side close to the doors.

The temperatures for the sensors in pallet positions L1, L11, R1 and R9 across all the products (technologies) differ significantly, as there are no common letters. For pallet positions L6 and R5, there are no significant differences between mean temperatures in the containers fitted with Technology 1 and 2 (letters 'h' and 'i', respectively). However, these differ significantly from the mean temperatures in the corresponding positions in the control containers (letter 'f' and 'h', respectively).

Table 3 summarises the average ambient temperature per cold-chain stage and pallet position for both similar (same technology) containers on both vessels. The 'overall' stage corresponds to the analysis above for the entire cold chain.

For pallet position RR9, hotspots occurred in the control containers through all the stages of the export cold chain, and at the arrival warehouse in the containers fitted with Technology 1, indicated in red. A pattern of temperature spikes is visible for the sensors in pallet position L11 for all containers throughout the cold chain, except at the cold store and arrival warehouse, indicated in orange. The highest temperatures experienced by the sensors within the containers equipped with Technology 2 were at pallet positions RR1 at the cold store and L11 at the origin port, indicted in purple. Temperature fluctuations were clear at the origin port, where the minimum mean temperature was below 0.25 °C and the mean maximum was 2.25 °C.

4.5. Container temperature breaks and duration

A temperature break was defined in Section 3.2 as any increase in temperature higher than 2 °C or any decrease below −1.5 °C for longer than 90 min. A sensor temperature break refers to a temperature break for an individual sensor, whereas a container temperature break can be defined as a continuous period where two or more sensors in a container displayed a temperature break.

The number of container temperature breaks and the duration of these breaks support the results of the ANOVA tests. The highest number of container temperature breaks was recorded in the control containers (Fig. 13 and Table 4). The origin port stage had the highest number of container temperature breaks, recorded in the control containers and all containers on the Maira. The sea route

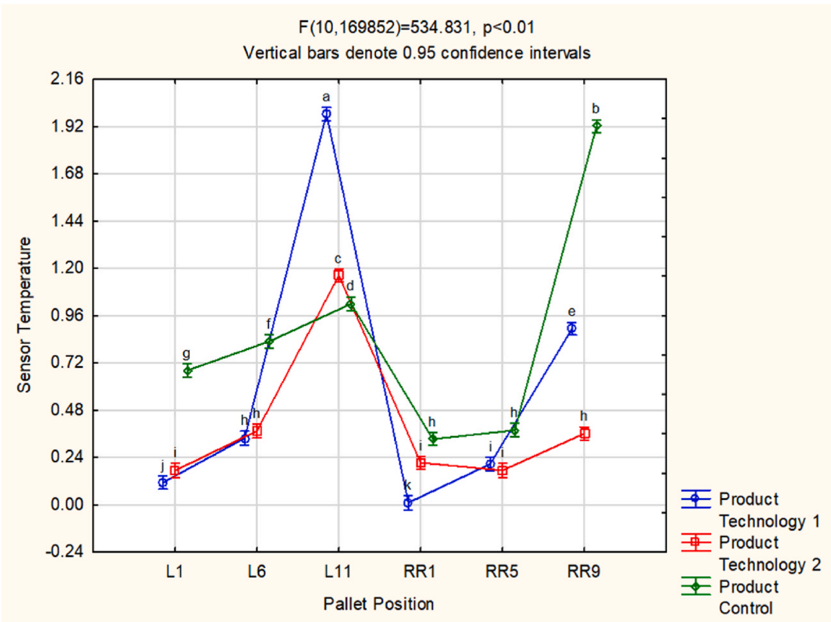

Fig. 12. Pallet position vs product least square means graph along all stages of the cold chain.

Table 3
Summary of the average temperatures (°C) per pallet position for each of the similar (same technology) containers on both vessels.

Stage	Pallet position	Control	Technology 1	Technology 2
Overall	RR1	0.33	0.01	0.21
	L1	0.68	0.11	0.17
	RR5	0.38	0.21	0.17
	L6	0.83	0.34	0.37
	RR9	1.92	0.89	0.36
	L11	1.02	1.98	1.16
Cold store	RR1	0.76	1.03	**1.58**
	L1	0.55	1.26	0.30
	RR5	1.35	1.05	0.99
	L6	0.63	0.74	0.10
	RR9	**1.36**	1.03	0.74
	L11	0.54	**1.02**	0.39
Origin port	RR1	0.85	1.20	0.74
	L1	1.14	1.71	0.75
	RR5	0.79	0.94	0.78
	L6	1.47	0.89	1.13
	RR9	**2.27**	1.61	0.95
	L11	**1.63**	1.19	**1.96**
Sea route	RR1	0.21	-0.20	-0.02
	L1	0.69	-1.12	0.05
	RR5	0.24	-0.07	-0.02
	L6	0.78	0.17	0.24
	RR9	**2.12**	0.65	0.23
	L11	**1.07**	0.54	0.79
Destination port	RR1	0.02	-0.45	-0.10
	L1	0.06	-0.22	-0.23
	RR5	-0.05	0.05	-0.29
	L6	0.28	0.12	-0.03
	RR9	**0.69**	0.32	-0.17
	L11	0.20	0.54	**0.71**
Arrival warehouse	RR1	0.11	9.18	0.05
	L1	0.11	1.39	-0.06
	RR5	0.10	1.22	-0.17
	L6	0.19	1.47	-0.04
	RR9	0.79	**9.94**	0.24
	L11	0.48	**11.10**	0.41

stage had the second highest number of breaks, where container temperature breaks were recorded in the control containers and to a lesser extent in all containers on the Paris. A few container temperature breaks were recorded during the cold store stage for all containers.

The average duration of container temperature breaks were calculated for each container as shown in Table 4. The average duration of container temperature breaks were also calculated for each stage of each container as shown in Fig. 14. The longest average breaks were recorded during the sea route stage, in the control containers and in the Technology 1 container on the Paris. The average breaks during all other stages were much shorter. Although the breaks during the sea route stage lasted the longest, the temperature deviations were much smaller than during the cold store and origin port stages (Figs. 9 and 10).

Fig. 15 illustrates the total number of sensor temperature breaks that were recorded by the various sensors in the top, middle and bottom layers of all containers on both the Paris and the Maira. These breaks are summarised in Table 5. The top sensors recorded the largest number of sensor temperature breaks in each container, except the one fitted with Technology 1 on the Maira, where the middle sensors recorded the largest number of sensor temperature breaks. The largest number of sensor temperature breaks was recorded in the control containers. For both vessels, the second highest number of sensor temperature breaks was recorded in the container fitted with Technology 1, whereas the least number of sensor temperature breaks was recorded in the container equipped with Technology 2. Most of the sensor temperature breaks in both containers occurred during the origin port stage.

Fig. 16 illustrates the total number of sensor temperature breaks recorded by the various sensors in pallet positions L1, R1, L6, R5, L11 and R9 of all containers on both the Paris and the Maira. These breaks are summarised in Table 6.

The highest number of sensor temperature breaks overall were recorded in pallet position R9. Most of these breaks occurred on the Maira.

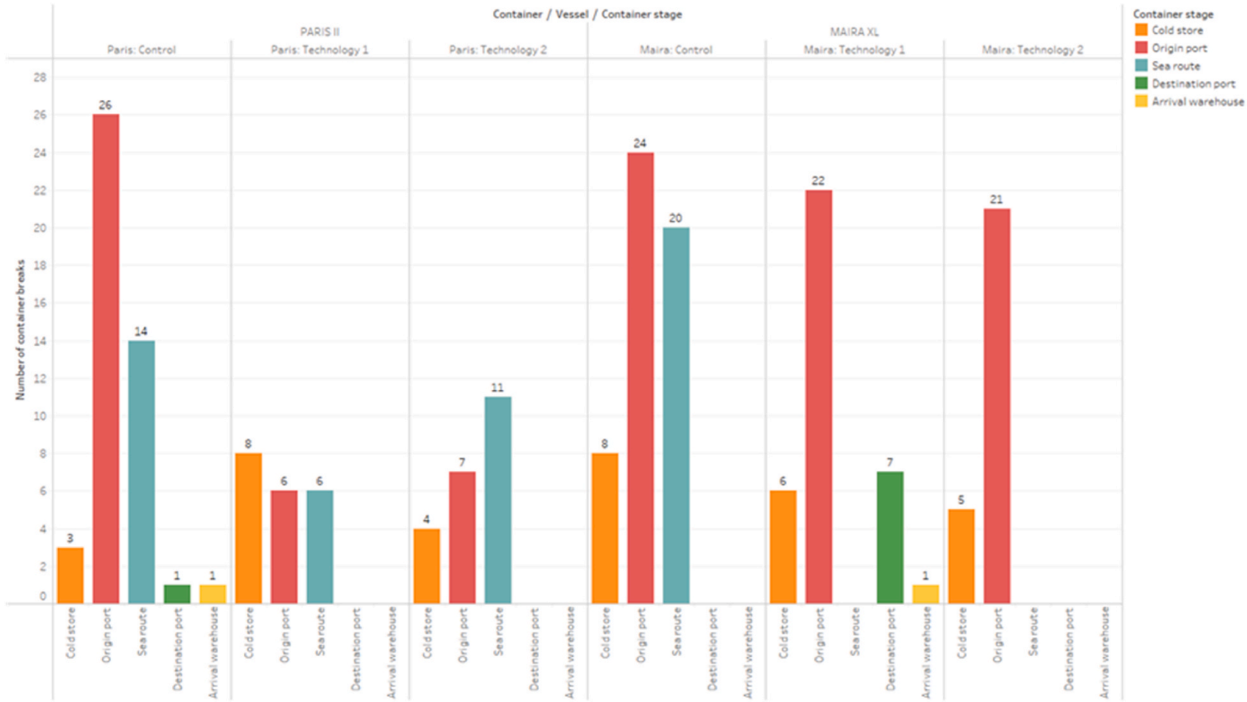

Fig. 13. Bar chart with the number of container breaks, per stage, for each container on the Paris and the Maira.

Table 4
Summary of the total number and average duration of container temperature breaks.

	Paris			Maira		
	Control	Technology 1	Technology 2	Control	Technology 1	Technology 2
Number of breaks	45	20	22	52	36	26
Average duration (hours)	31.22	13.12	3.85	20.35	10.75	8.92

On the Paris, the highest number of sensor temperature breaks were recorded for pallet position R1 (40), followed by pallet positions L11 (33) and R9 (30). The pallet position with the largest number of sensor temperature breaks in the control container and the container fitted with Technology 2 was R1. In the container fitted with Technology 1, it was R9.

On the Maira, the highest number of sensor temperature breaks were recorded for pallet position R9 (55), followed by pallet positions L6 (35) and L1 (34). The pallet position with the largest number of sensor temperature breaks in the control container and the container fitted with Technology 1 was R9. In the container fitted with Technology 2, it was L6.

4.6. Quality reports

Two containers transported more than one variety of table grapes, whereas the other four each transported a single variety. A specified number of punnets of each variety was selected for inspection from each container. Many factors, including the texture and consistency of the table grapes, colour, berry size, skin defects, sunburn, bruising, berry cracking and SO_2 bleaching and decay, were used to classify the grapes as shown in Table 7. Based on all these factors an overall score was allocated to each container according to the colour-coded measurement scale in Fig. 17. A summary of the results of all the containers is provided in Table 8.

In Fig. 17 the green status indicates up to fifteen days storage life, amber indicates up to eight days storage life and red indicates no storage life.

Both control containers were assigned a quality score of 4, which is 'below quality standard'. The problematic factors in these containers were decay, berry cracking and SO_2 bleaching. Containers fitted with Technology 1 received scores of 3–4 for two of the varieties and 3 for the third one. This gives an average score of 3.25 for the container on vessel Paris and an overall average of 3.375. The problematic factors were SO_2 bleaching (Paris) and berry cracking (Maira). Containers fitted with Technology 2 scored 3 for three of the varieties and 4 to 5 for the fourth one, which gives an average score of 3.5 for the container on vessel Paris and an overall average of 3.25. Problematic factors were berry cracking, SO_2 bleaching, skin defects and texture.

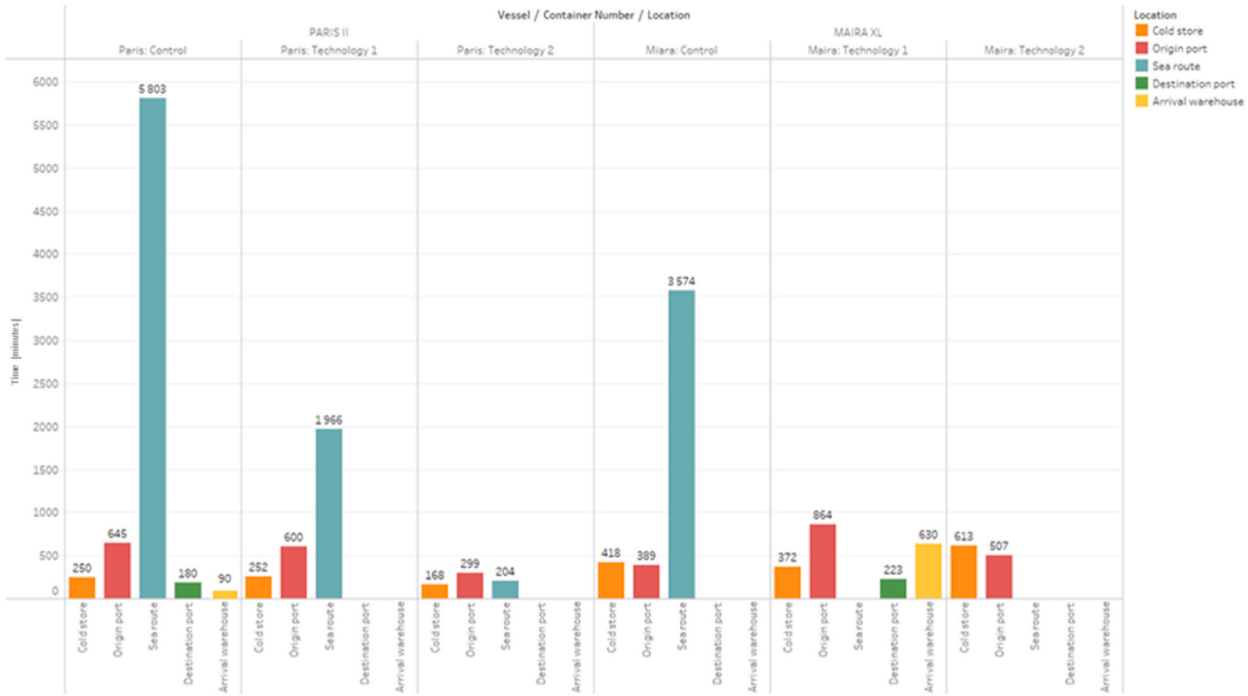

Fig. 14. Bar chart with average duration of container temperature breaks, per stage, for each container on the Paris and the Maira.

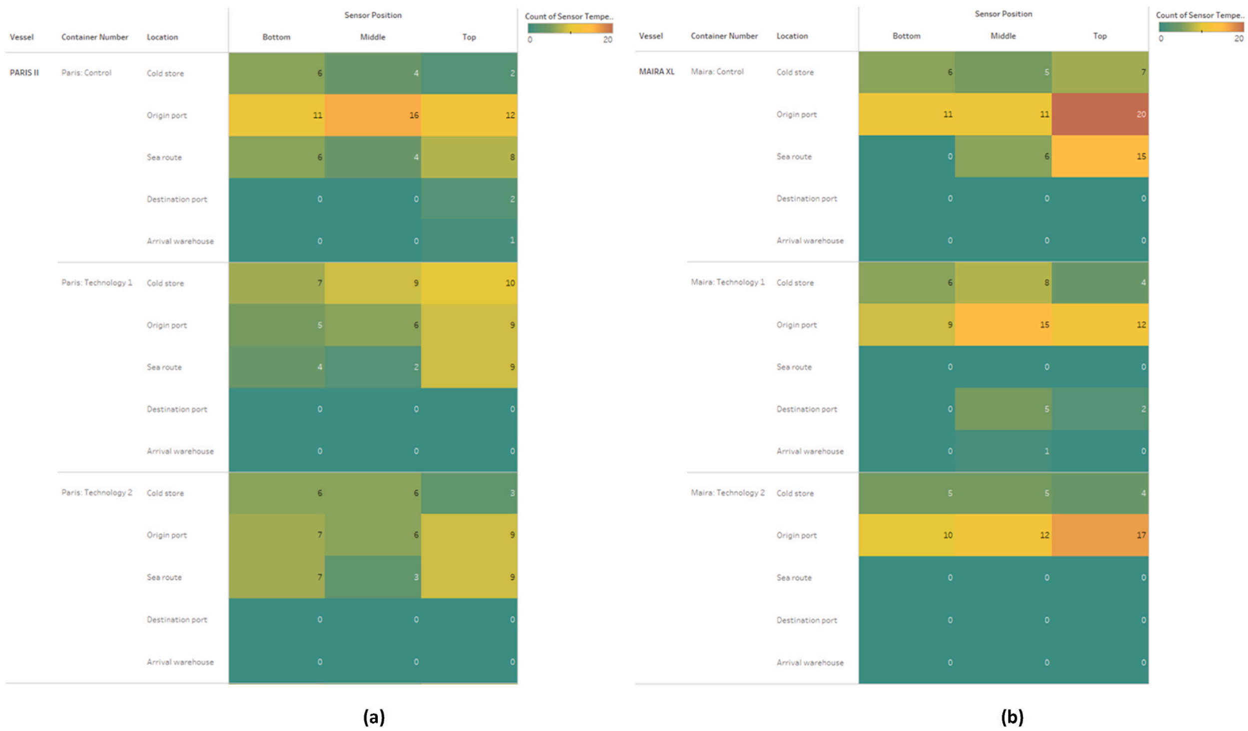

Fig. 15. Heat map with number of sensor temperature breaks, per stage and sensor position, for all containers on the (a) Paris and the (b) Maira.

Table 5
Summary of sensor temperature breaks per sensor position and container.

	Bottom	Middle	Top	Total
Paris: Control	23	24	25	72
Paris: Technology 1	16	17	28	61
Paris: Technology 2	20	15	21	56
Total	59	56	74	189
Maira: Control	17	22	42	81
Maira: Technology 1	15	29	18	62
Maira: Technology 2	15	17	21	53
Total	47	68	81	196
Grand total	**106**	**124**	**155**	**385**

(a) **(b)**

Fig. 16. Heat map with number of sensor temperature breaks, per stage, pallet position and technology, for each container on the (a) Paris and the (b) Maira.

Table 6
Summary of sensor temperature breaks per pallet position and container.

	L1	R1	L6	R5	L11	R9	Total
Paris: Control	12	16	13	14	12	5	72
Paris: Technology 1	11	10	8	8	11	13	61
Paris: Technology 2	6	14	7	7	10	12	56
Total	29	40	28	29	33	30	189
Maira: Control	12	8	17	6	10	28	81
Maira: Technology 1	14	4	8	8	10	18	62
Maira: Technology 2	8	9	10	9	8	9	53
Total	34	21	35	23	28	55	196
Grand total	**63**	**61**	**63**	**52**	**61**	**85**	**385**

5. Discussion

5.1. Temperature breaks

For all containers, temperature breaks were recorded in all the pallet positions during the origin port stage. These breaks were recorded by sensors in the bottom, middle and top layers of the pallets. Some container breaks were also recorded for all containers on the Paris during the sea route stage and for the control container on the Maira (see Fig. 13). On the Paris, the largest number of

Table 7
Extract from quality report for the control container on the Paris.

Aspect	Observation
Pulp temperature	+0.8°C to +1.3°C
Packing	5.00 kg cartons (10 x 500 g punnets)
First impression	Acceptable
Texture / consistency	90% firm, 10% slightly sensitive
Ripeness / maturity	100% turning / ripe
Colour	Light to full red
Stem colour	Mainly green
Brix readings	16.8 o 22.0%, average 19.4%
Berry size	Size L ; 18 to 25 mm, average 22 mm
Bunch size / form	Size L: small to large, average medium
Skin defects / deviations	Category 1: fair but generally within limits for the category indication
Sunburn / sunblush	Not found during inspection
Bruising	± 3-5% (to a light extent)
Packing / handling damage	± 3-5% (to a light extent
Berry drop	± 2-4%
Berry cracking	± 1-2% (to a very light extent
SO2 bleaching	± 5-10% (varying from a light to moderate extent)
Decay	Needs attention – 7 decayed pieces found out of 100 inspected punnets
Kind of decay	Botrytis, slip skin, sour-rot
General remarks	No remarks

Summary	Storage	Score	Colour
In view of the quality and condition problems as mentioned, clients' adverse comments / claims are to be expected	Short	4	

Source: [31].

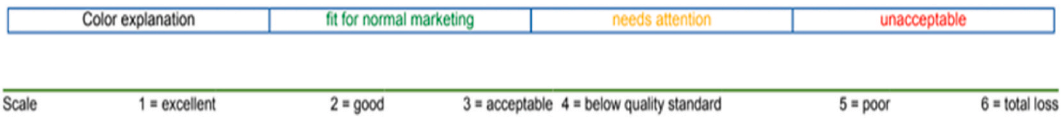

Fig. 17. Measurement scale.
Source: [31].

Table 8
Quality scores and problematic factors.

Vessel	Container	Number of varieties	Quality report score	Problematic
Paris	Control	1	4	Decay, berry cracking, SO_2 bleaching
	Technology 1	2	3–4; 3	SO_2 bleaching
	Technology 2	3	4–5; 3; 3	Berry cracking, SO_2 bleaching, skin defects
Maira	Control	1	4	Decay, berry cracking, SO_2 bleaching
	Technology 1	1	3–4	Berry cracking
	Technology 2	1	3	Texture, SO_2 bleaching

temperature breaks was recorded in pallet position R1 overall (see Table 7), especially for the control container. This might be because of sun exposure while the container was unplugged at the port. Overall, on the Maira, the largest number of temperature breaks was recorded in pallet position R9. This is the pallet closest to the container door, which, according to the literature and the interviewees, is the warmest area in reefer containers. Considering all containers, the longest temperature breaks were recorded in the control containers during the sea route stage.

From the analysis, it can be concluded that the control containers performed worse than the containers equipped with Technology 1 and Technology 2, and that the containers equipped with Technology 2 performed marginally better than those fitted with Technology 1. Even though the container equipped with Technology 2 on the Paris had two more container temperature breaks than the container equipped with Technology 1, much longer temperature breaks were recorded in the container equipped with Technology 1 than in the container equipped with Technology 2 (see Table 6). On the Maira, the container equipped with Technology 2 had fewer container temperature breaks of shorter duration in total than the container equipped with Technology 1 (see Table 6.)

5.2. Most significant cold-chain challenges

A significant finding was the temperature spikes that occurred during the cold store and origin port stages across all containers. During interviews, several industry experts pointed out a multitude of potential reasons for these spikes, such as insufficient capacity and incorrect loading of pallets into containers at cold stores, and inefficiencies, congestion and bad weather resulting in delays in connecting the reefers to a power source at the port and in loading of vessels.

Challenges pertaining to the cold store include employees not having experience of the installation process of the technologies in the reefer containers, resulting in longer installation periods, which increase the risk of temperature breaks. The researchers observed that the installation of Technology 2 took approximately 10 min longer than that of Technology 1. Incorrect installation will also reduce the effectiveness of the technology. Employees rarely load the container correctly; for example, pallets should not touch the container walls as the walls heat up when exposed to the sun.

The data analysis showed that sensors in the top layer of pallets recorded more temperature breaks than those in the middle or bottom layers. This could be because warm air always rises to the top of the container. The sensors in the bottom and middle layers recorded higher temperatures in the cold store. This could be because the top sensors are fully exposed to the cold air in the cooling facilities, which cools them down before the middle and bottom layers.

In addition, hotspots occurred in all refrigerated facilities, namely reefer containers and cold stores. Therefore, pallets should be rotated in the cold stores to ensure that they maintain the ideal temperature.

The fundamental challenges at the Port of Cape Town (origin port) include inclement weather and congestion, which could cause container trucks waiting in long queues for offloading at the port; inefficient equipment, which could lead to containers not being handled within the ideal time frame; labour behaviour, which could cause delays in containers being plugged into power sources and switched on upon arrival; and delays in handling paperwork due to shift changes. These challenges were exacerbated by the high daytime temperatures in South Africa during January and February when these trials were conducted.

The temperature breaks that were recorded during the sea route stage normally originate while the containers are being loaded onto the vessel, as they have to be unplugged from their power source during that time. Although most temperature breaks occurred during the origin port stage, the duration of the breaks during the sea route stage lasted much longer than those recorded at the origin port.

Few to no container temperature breaks occurred at the destination port in the Netherlands because the containers were offloaded at the Port of Rotterdam during winter. Further research is needed to get a more complete picture of events at the arrival warehouse, as the actual time at which the sensors were retrieved was not available.

6. Conclusions

The highest number of temperature breaks, which also on average lasted the longest, were recorded in the control containers. High temperatures and temperature fluctuations were most probably the causes of the quality issues found in the table grapes in these containers, namely berry cracking and decay. Berry cracking because of high temperatures was also the primary problem in the containers fitted with Technology 1. For one of the three table grape varieties in the Paris, Technology 2 received a worse score than any other container. The other two varieties carried on this vessel fared better or equal to the produce in the container fitted with Technology 1, and the issues found were not necessarily temperature related. The causes could be humidity, as the containers equipped with Technology 2 had fewer container breaks and their average duration was shorter.

Overall, the containers fitted with airflow technologies fared better than the control containers. The containers fitted with airflow Technology 2 performed marginally better than those fitted with airflow Technology 1. However, the sample size of this study was too small to draw definitive conclusions. Further research with larger sample sizes is required for more definitive results.

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CRediT authorship contribution statement

Margot Nel: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Leila Louise Goedhals-Gerber:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Esbeth van Dyk:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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