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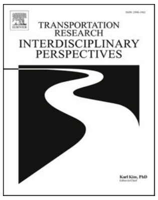

Identifying container hotspots for table grape exports from South Africa to the UK: A case study

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ABSTRACT

In view of table grapes being very sensitive to temperature variations, steps must be taken to maintain temperature at protocol levels to avoid deterioration of fruit quality and resultant food losses. This study assesses the implications of hotspots in refrigerated containers during table grape exports from a packhouse in South Africa, through the other stages of the cold chain until a retailer's distribution centre in the UK. Ambient and pulp temperature data were collected from temperature sensors inserted at locations distributed horizontally and vertically throughout the container.

The mixed analyses results showed that the most severe temperature deviations from protocol, in terms of the maximum temperatures recorded, occurred during the period from when the pallets were removed from cold storage to be loaded into the reefer container up to when the container was reconnected to an electricity supply at the port. Sensors located in the middle and top of the pallet were far more likely to record temperature deviations compared to sensors located at the bottom of the pallet, implying that hotspots are more likely to form in the upper-half of the container than near the floor.

The study, a first that covered the entire export cold chain of table grapes to the importing country's distribution centre, identified key areas industry role players can concentrate on to improve the operational procedures along the cold chain. This was done to help support the South African table grape industry to remain competitive in the global market.

1. Introduction

Globally, it is estimated that approximately a third of all food produced for human consumption (1.3 billion tonnes) ends up as food wastage annually. Fruit and vegetables are the food categories that make the largest contribution to food waste worldwide, with 38 % of all fruit and vegetables ending up as food waste (Statista, 2022; Van Bemmel and Parizeau, 2020). South Africa alone generates about 10 million tonnes of food waste per annum, with 44 % of all fruit and vegetables produced culminating in food loss or waste (WWF, 2017). This includes food loss owing to a reduction in mass or quality, which happens mostly during agricultural production and post-harvest handling and storage. The situation becomes more challenging when food, especially fresh fruit and vegetables, is moved in the export cold chain across national and international borders (Ndraha et al., 2018; Rodrigue and Notteboom, 2017).

Khumalo et al. (2021) note that the management of fresh fruit and vegetable cold chains represents the continuous process of temperature-controlled transportation and storage of chilled goods between the supply source and consumers with the aim of preserving quality of these products. They further acknowledge that the cold chain (comprising the pre-cooling stage, refrigerated transportation stage and, storage and handling stage) is crucial to the successful post-harvest movement of produce. According to Matare (2012) and Khumalo et al. (2021), the goal is to stop the deterioration of the fruit and improve shelf-life by preventing the microbial spoilage from yeast and bacteria. Similarly, Mercier et al. (2017) are of the view that cold chain efficiency is achieved when products deemed perishable are kept within acceptable temperature limits through adequate refrigeration. Thus, effectively controlling the temperature inside a shipping container is very

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important to the proper functioning of the cold chain.

Maintaining external fruit quality shapes consumer choice and, for that matter, market price, whereas maintaining the internal quality of fruit is deemed essential for retaining consumers (Ladaniya, 2008; Torres et al., 2017). Temperature is by far the most important environmental factor that has the highest impact on the rate of deterioration and expected market life of fresh produce and can, therefore, be translated into financial loss should quality loss occur (Freiboth et al., 2013; Thompson et al., 2008; Watada et al., 2005). For instance, Piljac-Žegarac and Šamec (2011) report that compared to being stored at room temperature, fruits like cherries, red currants, drupes, and raspberries lost less mass and nutritional value when stored in refrigerated containers at 4 °C.

Aung and Chang (2014) note that table grapes are very temperature sensitive. Once their temperature has been decreased when they enter the cold chain, the temperature should not increase again as it would be detrimental to the quality of the grapes. The pulp temperature affects the fruit quality, through features like the taste and shelf-life, which then impacts the price (Fedeli et al., 2022). However, a significant volume of table grapes is shipped over long distances from warm-climate countries such as South Africa to cold-climate countries such as the United Kingdom (UK) and the Netherlands. This poses problems with maintaining temperature at protocol levels in the export cold chain.

Studies show that produce losses occur at various stages of the supply chain, depending on the global location. Whereas losses are mainly evident at the supermarket and consumer stages in developed nations, this happens at the post-harvest and distribution stages in developing countries (Kitinoja and Kader, 2015; Porat et al., 2018; Goedhals-Gerber and Khumalo, 2020). According to Mercier et al. (2017) and Chaomuang et al. (2022), even though temperature control throughout the export cold chain through refrigeration makes it possible to delay the deterioration of produce quality, temperature control through refrigeration still poses significant challenges. Various studies conducted in developed countries have observed that temperature breaks occur throughout the entire cold chain, especially the transport and retail stages (Ndraha et al., 2018). Even if they last only a few hours, they may significantly affect product sensory quality (Loisel et al., 2021). The few field studies undertaken in developing countries indicate that a similar trend has been observed in South Africa in the table grape, pome and citrus industries (Freiboth et al., 2013; Goedhals-Gerber et al., 2015; Goedhals-Gerber et al., 2017; Goedhals-Gerber and Khumalo, 2020).

Existing studies on table grapes and related fruits have mostly focused on selected segments of the export cold chain, with only a few studies covering all four stages (packhouse to cold store; reefer stack; sea route and distribution centre) of the cold chain (see Table 5 for a description of the four stages). Freiboth et al. (2013), for example, explored the packhouse to cold store and reefer stack stages of the summer fruits cold chain (grapes, apples and pears); Goedhals-Gerber et al. (2015) examined the influence of logistics activities on breaks along the packhouse to cold store and reefer stack stages of the table grape, plum and pome fruit export cold chain; Goedhals-Gerber and Khumalo (2020) focused on temperature deviations in the export cold chain for navel orange from orchard to packhouse to cold store and sea route and Goedhals-Gerber et al. (2021) investigated how severe temperature breaks are from the packhouse to the importer's distribution centre of the apple and pear export cold chain. It is evident that none of the studies concerning grapes covered all four stages.

The research questions for this study are as follows: 1) Where and with what frequency do temperature breaks occur within the table grape cold chain from the exporting country to the importing country? 2) What is the duration of the temperature breaks? 3) In what positions inside a container are hotspots more likely to occur?

This study improves on existing ones in the table grape industry by assessing the implications of container hotspots for exports. It traced the cargo from a packhouse in South Africa to the distribution centre of a retailer in the UK in 2021. The article analyses ambient and pulp temperature data collected from temperature sensors that were inserted in six pallets per container. The sensors were inserted on three levels (bottom, middle, top) in a pallet and the pallets were spread along the length of the container (two at the closed end near the cooling unit, two in the middle and two at the doors). This enabled an analysis of the temperature variation along the length of the container as well as the variation within a pallet (bottom, middle and top).

The study also determined the segment(s) of the export cold chain in which the temperature breaks were most severe. This is crucial as it will provide key role players in the industry with the information needed to minimise the risk of quality loss due to deviations from temperature protocols and so create a more efficient cold chain. It also identified areas along the export cold chain for table grapes which the industry can focus on for operational procedures improvement, and areas for possible research in the future.

2. Literature review

1.1. Table grape export cold chain

A cold chain, according to Rodrigue and Notteboom (2017) refers to a supply chain for temperature-controlled national and transnational trade in perishable goods. Studies point to the fact that properly monitoring and managing temperature post-harvest, from when it is harvested to when it is consumed, are critical elements in the cold chain. It prevents fruit deterioration and ensures shelf-life is optimised by reducing the rate of respiratory maturation and preventing microbial spoilage (Matare, 2012; Arah et al., 2015; Berry et al., 2016; Goedhals-Gerber and Khumalo, 2020). For this study, the Perishable Product Export Control Board (PPECB) definition of a cold chain is used, namely "the seamless and uninterrupted movement of fresh, chilled or frozen products, from the production area to the market, through various storage and transport mediums, without any change in the optimum storage temperature and relative humidity" (PPECB, n.d.).

The literature notes that a fundamental requirement in the transport of temperature-sensitive products is the need for temperature control (Todd, 2017) and maintaining optimal temperature conditions, in agreement with the relevant requirements and guidelines. This requires a number of processes to be put in place to preserve perishable products from the point of production to the point of consumption (Mataragas et al., 2012; Laguerre et al., 2013; Fedeli et al., 2022). Thus, understanding the essential role temperature plays in a cold chain is of vital importance to its success (Fedeli et al., 2022). A pictorial depiction of the export cold chain for table grape is shown in Fig. 1.

Fig. 1 illustrates that the typical table grape export cold chain begins where the freshly harvested grapes are put into crates on the farm and moved to a cooled room (usually a packhouse located on the farm) to remove any field heat. According to Freiboth et al. (2013) this process known as pre-cooling, is crucial to the preservation of the fruit quality. Once the post-harvest process of lowering fruit temperature begins, it must be continued, in order to prevent a disruption in the cold chain as well as to maintain quality, ensuring the end consumer receives the highest quality product. The grapes are then packed into cartons, which are stacked in layers onto pallets and transported to a regionally-located cold store where the fruit pulp temperature is reduced to −0.5 °C through a process known as forced-air cooling (FAC). The pallets are kept in cold-storage rooms to keep the pulp temperature at −0.5 °C, in line with the PPECB procedure for handling table grapes (PPECB, 2022c).

The PPECB is a national public entity responsible for produce quality, phytosanitary and food safety inspections as well as for establishing protocols for temperature management, handling, transport and storage of perishable products exported from South Africa (PPECB, n.d.). The PPECB inspects internal and external fruit quality and adherence to market requirements at the packhouse.

The PPECB conducts pre-trip inspections according to ISO standards

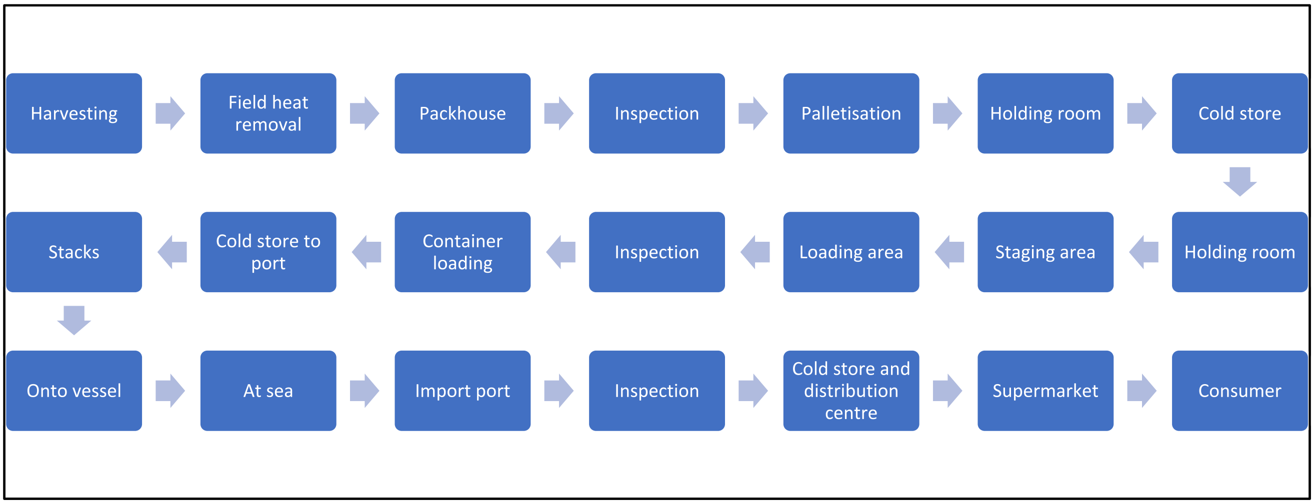

Fig. 1. Pictorial depiction of table grape export cold chain. Source: Adapted from Fresh Produce Exporters' Forum, 2016.

on refrigerated trucks and refrigerated containers used for the transport and export of perishable products. The PPECB also inspects and certifies cold stores to ensure adherence to food safety and cold chain management. Refrigerated containers, commonly called reefer containers, are used for shipping because they have adjustable temperature settings ensuring a wide range of perishable products are accommodated (Rodrigue and Notteboom, 2015; Goedhals-Gerber et al., 2017). Hamburg-Süd (2016) notes that this type of container has the ability to keep required temperatures within a maximum range of about −30 °C to +30 °C, depending on the type of reefer. The loading process commences once the grapes have reached protocol temperature and the reefer stacks in the port are opened to receive containers for the vessel on which the grape container has been booked. Before loading fruit into the reefer containers at the cold store, the PPECB does a final check on fruit pulp temperature and pallet stability.

The main aim of the container is to keep the fruit at protocol temperature because if the fruit pulp temperature is too warm, the reefer container is unable to reduce it to protocol levels (Fresh Produce Exporters' Forum, 2016). The refrigeration unit is located at the closed end of the container. Cold air enters the container through vents near the floor, from where it circulates through and around the pallets to the container doors. As the air circulates through the fruit, it removes the respiratory heat. The warmer air rises to the roof of the container, from where it flows back to the refrigeration unit to be re-cooled. In addition, the pallets have to be placed inside the container in such a way as to ensure the flow and circulation of air is adequate (Hamburg-Süd, 2016). Berry et al. (2016) argue that failure to adhere to this requirement can make it difficult to get rid of respiratory heat. The issues identified could lead to hotspots inside the reefer container, which ultimately could be damaging to the fruit.

It is only ideal to pre-cool the container before loading if the loading bay at the cold store has airlocks. In a personal interview in De Doorns, South Africa, in 2018, Mr Jacobs argued that pre-cooling when airlocks are not available can lead to condensation in the container, which can result in sulphuric acid burn on the grapes (Fedeli et al., 2022). The next stage involves transporting the reefer container to the departure port. At this point, the grapes' pulp temperature has to be at −0.5 °C and this has to be maintained throughout the container's voyage according to the PPECB protocol (PPECB, 2022b). Hence, during periods when a regular supply of power is not available, for instance when being conveyed by truck, external power sources like a diesel-powered generator (genset) are used to power the reefer refrigeration unit. However, where the journey to the port is shorter than two hours, a power supply is not required (Fedeli et al., 2022).

On arrival at the port, the containers are stacked in a reefer stack equipped with a power supply for each reefer. The reefer temperature is monitored throughout its stay (Goedhals-Gerber et al., 2015). The total time that the reefer is without power during the transition process (cold store to the reefer stack) should be reduced to a minimum to prevent temperature spikes. The reefer has to be disconnected from the reefer stack when it is ready for loading and connected to the vessel's power supply once it has been loaded. Upon arrival at the destination port, the process is reversed and the reefer is delivered to the importer's distribution centre where the pallets are offloaded and the cartons removed. The cartons of fruit are then sold to end consumers through retail outlets.

Thus, per the study carried out by Khumalo et al. (2021), it is evident that this cold-chain process involving pre-cooling, refrigerated transportation and handling of stored products are considered key factors in the successful movement of fresh fruit post-harvest.

A summary of empirical studies undertaken on various products focusing on the issues associated with one or more segments of the fruit export cold chain from South Africa is presented in Table 1. The findings from the research highlighted below were used as inputs to the guide the scoping of the research conducted in this paper.

In this section, the literature has highlighted the challenges involved in maintaining fruit temperatures to a minimum if exposed to warmer temperatures during transfer from one cold chain unit to another (Wu et al., 2018). This is particularly relevant if the cooling process has already started. In addition, Brooke and Du Plessis (2016) outline other key contributors to the deviations from temperature protocol in fruits. They include packaging, lack of conformity between pallet designs and packaging guidelines, and adjustment of the temperature setting of the container according to the PPECB protocol during the sea route.

These issues need to be resolved or kept to a minimum, otherwise they can result in non-conformance in the export cold chain. A summary of empirical studies and industry guidelines that focus on the issue of non-conformance are discussed in section 2.2.

1.2. *Framework based on the cold-treatment engagement process for fruit*

During a thorough literature review, a framework was identified to address potential non-conformance issues in the cold chain (Khumalo et al., 2021). For this research, the framework from Khumalo et al. (2021) was adapted based on the cold-treatment process involving three phases: pre-cooling, loading of pallets into a container, and fruit pulp/ambient temperature stabilisation, to ensure that temperature protocols are adhered to and that temperatures are kept within the required range.

- **Pre-cooling phase**

Table 1
Summary of studies according to the stage of the cold chain and type of product.

Stage of the cold chain	Scope and main findings	Product	Methodology	Reference
o Stage 1: Packhouse to cold store o Stage 2: Reefer stack	o To identify key problem areas in the supply chain (packhouse to port of export) accountable for temperature breaks in the South African summer fruit cold chain. - Approximately 73% of reefer containers experienced a temperature break while in the port of departure. - Approximately 13% of reefer containers experienced a temperature break during transportation to the port. - The ambient temperature was lower for pallets located at the closed end of the container compared to those closer to the door.	Summer fruits: Grapes, apples and pears	Quantitative:Statistical analysis based on historical and trial shipment temperature data.	Freiboth et al., 2013
o Stage 1: Packhouse to cold store o Stage 2: Reefer stack	o Examined the influence of logistics activities on temperature breaks (that is, percentage and duration) along the packhouse to cold store and reefer stack stages of the table grape, plum and pome fruit export cold chains o Significant number of temperature breaks occurred at the interface between the cold store and the truck. - Findings identified 183 breaks in the 123 reefer containers – only about 11% experienced no temperature breaks, 49% experienced one break, while the remainder experienced two or more breaks. - Majority of the breaks occurred along the transport segment followed by the container stack segment. - Many breaks lasted longer than a day. o Developed a “Best Practice Guide” for the table grapes industry.	Pome fruit, table grapes and plums	Mixed method (quantitative and qualitative): - Statistical analysis of historical temperature data for 123 reefer containers. - Conducted 11 temperature trials. - Observed processes at key stages of the cold chain including farms, cold stores and the port of departure.	Goedhals-Gerber et al., 2015
o Stage 2: Reefer stack	o Examined the causes of temperature breaks inside the Cape Town Container Terminal (CTCT). - 493 containers were studied. - 81% of the temperature breaks happened in the CTCT. - The average time taken to plug the container into a power source in the terminal was 1 hour 52 minutes, almost three times the recommended time of 40 minutes. - Almost 76% of containers were not connected to an electric supply within 40 minutes and for 15% it took over 3 hours before being connected. - Approximately 20% of the containers did not experience any breaks. - However, 22% of containers did not cool down to the protocol temperature. - 41% of trucks arrived between 12:00 and 15:00, when fewer workers were available owing to lunch breaks and change of shifts.	Table grapes, summer pears and plums	Mixed method (quantitative and qualitative): - Graphical analysis of temperature trials and temperature data from 493 containers - Primary research: Personal interviews, 12 weeks of observation at the Port of Cape Town. - Secondary research: Desktop survey and information on procedures at the port.	Goedhals-Gerber et al., 2017
o Stage 1: Orchard to packhouse to cold store o Stage 2: Sea route	o Investigated temperature deviations in the export cold chain for navel oranges from the orchard to the port of destination in the USA. Inserted temperature sensors to measure pulp and ambient temperatures in three layers (top, middle and bottom) of pallets. - Temperature spikes occurred while the fruit dried in the sun after drenching and when being transported to the Cape Town Container Terminal. - Temperature breaks were measured during inspection in the cold room and during loading of the pallets onto the vessels. - On commencement of the cold-sterilisation protocols, no temperature breaks were recorded on the reefer vessels.	Navel orange	Quantitative: ■ Statistical analysis of historical temperature data and through trials; shipments divided into two phases.	Goedhals-Gerber and Khumalo, 2020;
o Stage 1: Packhouse and cold store o Stage 2: Reefer stack o Stage 3: Sea route o Stage 4: Distribution centre	o Analysed how severe temperature breaks were in the export cold chains for apples and pears from the packhouse to the first distribution centre in the Netherlands. o Inserted temperature sensors to measure fruit pulp temperature in the top, middle and bottom layers of six pallets located at the back (closed end), middle and front (door end) of the container. - Variations in temperature data were analysed for different layers in pallets and pallet locations.	Apples and pears	Mixed method (quantitative and qualitative): - Conducted 12 temperature trials - Statistical analysis of temperature data using Statistica. - Primary qualitative data: through observation and informal interviews at key facilities such as farms and packhouses, distribution centres and port terminal.	Goedhals-Gerber et al., 2021

(*continued on next page*)

Table 1 (*continued*)

Stage of the cold chain	Scope and main findings	Product	Methodology	Reference
	• The findings show that majority of the temperature breaks were logged in the packhouse, which is undesirable given the pome fruit had been kept frozen for a significant period prior to being packed. • Further breaks were reported in the CTCT and during the transportation of the containers in the Netherlands on barges with no power supply.			
o Stage 1: Packhouse and cold store o Stage 2: Reefer stack o Stage 3: Sea route o Stage 4: Distribution centre	o Analysed how severe temperature breaks were in the table grapes export cold chains from the packhouse to the importer's storage facility in the UK. o Inserted temperature sensors to measure fruit pulp and ambient temperature in the top, middle and bottom layers of six pallets located at the back (closed end), middle and front (door end) of the container. • Variations in temperature data were analysed for different layers in pallets and pallet locations. • The findings show most of the temperature breaks were logged at the cold storage facility during loading of containers and at the CTCT. • No temperature deviations were recorded at the distribution centre in the UK.	Table grapes	Mixed method (quantitative and qualitative): • Conducted 12 temperature trials • Statistical analysis of temperature data using Statistica. • Primary qualitative data: through observation and informal interviews at key facilities such as farms and packhouses, distribution centres and port terminal.	Fedeli et al., 2022

The pre-cooling phase covers post-harvest heat removal (Mercier et al., 2017; Elansari et al., 2019). Dehghannya et al. (2010), Defraeye et al. (2014) and Elansari et al. (2019) note that not only is it one of the most efficient procedures of preserving the quality of a product but also a vital step in the cold chain because post-harvest product and storage quality together with shelf-life are strongly impacted by the temperature of a product. Dehghannya et al. (2010) state that this procedure also reduces the processes for bacterial and fungal build-up thereby preserving fruit properties like texture and flavour during storage.

- **Loading of pallets into a container**

During this phase, the use of reefer containers has become the standard temperature-controlled means of transporting perishable products such as fruit. Van Marle (2020) observes that about 85 % of citrus fruit shipped to international markets from South Africa was transported using reefer containers. An international container logistics crisis has resulted in a shortage of reefer containers for fresh fruit export from South Africa. In 2022, table grape exporters have returned to using conventional reefer vessels between South Africa and Europe on a small scale (Eurofruit, 2022) compared to 2020, when 100 % of table grapes were exported to Europe via reefer containers (Jansen, 2022).

- **Fruit pulp/ambient temperature stabilisation phase**

The fruit pulp/ambient temperature stabilisation phase starts as soon as the fruit is loaded into the container and transported to the departure port, where the containers are stored in a reefer stack till they are loaded onto the vessel. It also includes the sea voyage until the port of destination is reached. During this entire phase, strict temperature protocols have to be adhered to as required by the particular export market. A detailed summary of each phase, along with findings of empirical studies and industry guidelines and requirements, is presented in Table A.1 in Appendix A.

1.3. *Gaps in literature and contribution of the study*

The empirical literature has highlighted a number of studies in the fruit industry that covered one or more segments of the export cold chain and used either qualitative or quantitative analysis or both. For example, the Freiboth et al. (2013) study employed statistical analyses to investigate key sections of the first two segments of the supply chain responsible for summer fruit temperature breaks (grapes, apples and pears) cold chain. Similarly, Goedhals-Gerber and Khumalo (2020) used statistical analyses involving time series plots of historical temperature data and temperature trials to examine temperature deviations in the navel orange export cold chain covering the orchard to packhouse to cold store, reefer stack and sea route stages. The Goedhals-Gerber et al. (2021) study went a step further by adopting a mixed-method approach to analyse how severe temperature breaks are in the pear and apple export cold chain from the packhouse to the importer's distribution centre in the country of destination.

Regarding potential issues with lack of conformance in the export cold chain, section 2.2 reviewed empirical work following these three phases: pre-cooling, container loading and fruit pulp/ambient temperature stabilisation. Mercier et al. (2017) note that pre-cooling perishables immediately post-harvest has been proven to increase their shelf-life significantly, since perishable goods have the highest temperature during the period after harvesting. Thus, this period carries the highest risk of potential loss of shelf-life. Similarly, handling processes vary according to product type, which could lead to different issues in the cold-chain. For example, according to Khumalo et al. (2021) fruits like plums and pears are often cooled in advance in crates and put in cold storage until there is a market demand before being packed for export. For the container-packing phase, the PPECB (2022a) states that the requirements for markets like USA and China include, among others, that two or more air temperature and pulp temperature sensors be fitted in at least three specified locations in the container.

The study differs from other table grape studies in that it covers the entire cold chain (packhouse to distribution centre) by assessing the implications of container hotspots for exports, from the exporter in South Africa to a retailer in the UK. The methodology adopted goes beyond the normal descriptive statistical analysis of previous studies (Fedeli et al., 2022, Freiboth et al., 2013, Goedhals-Gerber et al., 2015) by using econometric modelling (logit model) to investigate the effect of a horizontal distribution of sensors along the length of the container and a vertical distribution of sensors in pallets on the likelihood of temperature breaks being registered. This study expands on the one by Fedeli (2022) by inserting probes in six pallet positions per container instead of two and by placing the ambient temperature loggers close to the container wall and the centre line of the container instead of halfway between the wall and the centre line.

Similarly, the cold-treatment process has been adapted to this study by employing the three phases (pre-cooling, container packing and fruit pulp / ambient temperature stabilisation) to cover all four stages involved in the grapes export cold chain, from the exporters farm to the importer's distribution centre (see Table 5). Adhering to and following these processes are crucial to ensure that any potential non-conformance is avoided.

3. Research design

2.1. Methodology

The research adopted a mixed-method approach, that is, both quantitative and qualitative data was used to undertake the analyses. The specific mixed-method approach used was facilitation (Bryman et al., 2016): qualitative data including observations at packhouses and cold stores and semi-structured interviews with key role players along the cold chain was used to support the quantitative analysis.

Primary quantitative information was collected through the data logged by temperature-monitoring sensors, namely Sensitech TempTale Radio Frequency (RF) and TempTale 4 Probe Sensors. RF sensors monitor the ambient temperature to which the grapes are exposed, whereas the probe sensors monitor the internal temperature of the product (grape pulp temperature, in this case). The temperature sensors were inserted in South Africa (that is, packhouse or at the cold store) and were tracked throughout all stages of the journey until being removed at the retailer's storage facility in the UK.

There are two ways (invasive or non-invasive) in which temperature sensors can be inserted. For fruits, the invasive approach captures pulp temperature through a stainless-steel probe. Specifically, for table grapes, a few berries are skewered onto the probe. However, this method leads to the loss of that particular fruit. In the case of the non-invasive approach, an ambient temperature sensor is placed among the fruit inside the carton, to expose the sensor to the fruit's environment (Fedeli et al., 2022). To make it easy to identify the sensors in the cartons, long white ribbons are attached to the sensors. Sensors could be located by pulling the ribbon, making it quick and easy to retrieve them.

In this study, the invasive method was used to collect the fruit pulp temperature and the non-invasive method to collect the ambient temperature to which the grapes were exposed to form a true picture of the temperature profile for the entire cold chain for grape exports. These methods are based on widely accepted industry standards that have been tried and tested through previous studies in the industry (Khumalo et al., 2022; Mercier et al., 2017; Goedhals-Gerber et al., 2015). They are frequently supported by the internal quality control and assurance procedures put in place by industry players. Data analysis was undertaken through a combination of simple descriptive statistics and more advanced logit regression models. The temperature sensors were retrieved by the retailer and the University of Hull. The data collected by some of the RF devices was automatically read by the RF readers at the retailer's distribution centre, whereas the probe sensor data and the data on some of the RF devices were manually downloaded by the University of Hull. The data was uploaded to a secure cloud-based database, where after it was downloaded and exported to Excel for analysis purposes.

Descriptive statistics were used to determine the distribution of ambient and fruit pulp temperatures as well as the number and duration of temperature breaks along the export cold chain. The logit regression model was used to investigate the effect of the locations of sensors and pallets in the containers on the likelihood of temperature breaks being registered. The raw sensor temperature distribution data could not be used for the logit analysis. Two new variables were defined to capture the temperature breaks for the ambient and pulp sensors, respectively – that is, every occurrence during which the temperature readings increase above 2 °C or decrease below −1.5 °C for a period of 90 min or more. This data was used to generate binary dependent variables for the ambient and probe sensors, assuming dichotomous values (1 = if a temperature break is recorded and 0 = if otherwise). Hence, the set of outcomes with only two possibilities provides a binary set (Strickland, 2017) and is the motivation for the choice of a binary logit model specification as the linear regression model is not ideal for predicting categorical dependent variables.

In the generic form of the logit model, the dependent or response variable Y is a dichotomous (binary) variable, meaning it takes on only one of two values (0 or 1). Hilbe (2015) notes that the logit regression is based on the Bernoulli distribution, a distribution of 1 s and 0 s. Thus, following Gould et al. (2010) the probability function from the Bernoulli distribution is

$$f(y_j;\pi_j) = \begin{cases} \pi_j & if\, y_j = 1 \\ 1-\pi_j & if\, y_j = 0 \end{cases} \tag{1}$$

where $0 \le \pi_j \le 1$ and π_j is the probability that $y_j = 1$ (1 shows a success or that the event of interest has occurred). The logit model uses the log of the odds ratio (the logit function) to describe the relationship between the independent variable x_j and π_j by

$$h^{-1}(\pi_j) = ln\frac{\pi_j}{1-\pi_j} = X_j\beta \tag{2}$$

which can be rewritten as the cumulative distribution function

$$\pi_j = h(X_j\beta) = \frac{e^{X_j\beta}}{1+e^{X_j\beta}} = \frac{1}{1+e^{-X_j\beta}} \tag{3}$$

This particular function is commonly referred to as the logistic function or inverse logit function.

The log-likelihood function is given as (Gould et al., 2010):

$$lnl_j = \begin{cases} \ln h(X_j\beta) & if\, y_j = 1 \\ \ln h(-X_j\beta) & if\, y_j = 0 \end{cases} \tag{4}$$

where $Y_j = 1$ if the ambient temperature rises above 2 °C or drops below −1.5 °C for 90 min or more; and

$Y_j = 0$ if the ambient temperature falls outside the above ranges.

To validate the logit model, various tests can be undertaken to ascertain how well the data fits the model, that is, analysing the goodness of fit of the model. In that regard, the Hosmer-Lemeshow test is a chi-squared-like goodness of fit test for the logit model (Hosmer, et al., 1997); specifically it calculates how well the observed event rates match the expected event rates in population subgroups. The test statistics follow a chi-squared distribution with a large chi-squared value (with small p-value < 0.05) indicating a poor fit and a small chi-squared value (with large p-value > 0.05) indicating a good fit (Hosmer and Lemeshow, 1980).

Other tests like receiver operating characteristic (ROC) analysis allows the quantification of the accuracy of diagnostic tests that enables discrimination between two conditions (referred to as normal or abnormal). Thus, a ROC curve can be used to evaluate the performance of a diagnostic test over the range of possible cutpoints for a binary predictor variable using measures of sensitivity and specificity (Mandrekar, 2010). Likewise, the area under the ROC curve (AUC) gives an effective way to summarise the overall diagnostic accuracy of the test with values ranging from 0 to 1 where a value of 0 indicates a perfectly inaccurate test and a value of 1 reflects a perfectly accurate test.

In addition, the logit model was compared to the alternative probit model using two information criteria, namely Akaike's Information Criteria (AIC) and Schwarz's Bayesian Information Criteria (BIC). AIC can be defined as a measure of the goodness of fit of any estimated model whereas BIC is used for model selection amongst parametric models. Given two models, the one with smaller AIC and BIC indicates a better fitting model.

2.2. Data collection

The industry partners included grape exporters who have contracts with grape farms/packhouses and a retailer who imports the grapes and owns the distribution centre. Where possible, the temperature was tracked from the packhouse, otherwise from the exporter's cold store (South Africa) through the entire cold chain until arrival at the retailer's distribution centre in the UK.

Temperature sensors were inserted into four containers with table grapes. Each container had sensors in six pallets. One RF-enabled ambient temperature sensor was inserted in the top layer, middle layer and the bottom layer of each pallet. These sensors were inserted on the side of the pallet that would be loaded next to the container wall. In addition, one RF-enabled ambient temperature sensor was inserted per pallet in the top layer of three pallets – on the side of the pallet that would be close to the centre line of the container, as illustrated in Fig. 2.

TempTale 4 Probes were employed to record table grape pulp temperature readings. One probe was inserted in the top layer of each pallet, on the side of the pallet that would be loaded next to the container wall. Thus, 21 RF sensors and six probe sensors in total were inserted per container. The pallets with sensors were positioned at various locations along the length of the container (closed end – near the refrigeration unit, middle, and door end), as illustrated in Fig. 2 below.

In this study, 20 pallets in total were loaded into a 40′container with the standard dimensions sanctioned by the International Organisation for Standards (ISO). Of the six pallets containing sensors, three were loaded on the left (L1, L6, L11) and three on the right (R1, R5, R9) side of the container (Pattanaik and Jenamani, 2022; Struth, 2001). Fig. 2 shows the top view of the pallet configuration.

Various stickers and ribbons were used to show the location of sensors and the side of the pallet that should face the wall of the container (see Fig. 3):

- White ribbons attached to sensors showed the exact locations of sensors.
- Fluorescent yellow stickers attached to all sides of the pallet showed the levels (bottom, middle and top) containing sensors (i.e. 12 fluorescent stickers per pallet) (Fig. 3c, d and e).
- White stickers on the middle level showed the pallet side facing the wall (Fig. 3d).
- Blue dot stickers showed the pallet number (e.g. R9) (Fig. 3e).

The researchers managed to retrieve 91 % of the sensors – a few sensors in the first shipment of grapes to the UK were lost.

4. Data analysis and results

The data analysis focused on temperature breaks. The definition of a temperature break in the table grape cold chain refers to every occurrence during which the temperature readings increase above 2 °C or decrease below −1.5 °C for a period of more than 90 min. A temperature spike occurs when the above condition of a temperature break is satisfied, but for a duration shorter than 90 min. These definitions were developed in consultation with the table grape industry in South Africa during previous studies and are now accepted definitions of the country's table grape industry (Freiboth et al., 2013; Goedhals-Gerber et al., 2015; Fresh Produce Exporters' Forum, 2016). An important feature of temperature breaks is that they are cumulative: several combinations of short breaks can have the same harmful effect on the quality of a fruit as a large break (Freiboth et al., 2013).

In this paper, the analyses performed for one of the table grape shipments from the South Africa to the UK are discussed. Table 2 shows its shipping information.

For data-gathering and analysis purposes, the table grape cold-chain steps (or "sections") were grouped into four stages, namely packhouse to cold store, reefer stack, sea route and distribution centre. Table 3 summarises these stages.

Fig. 4 depicts the average ambient temperature (measured with RF sensors) and fruit pulp temperature (measured with probe sensors) inside the cartons of grapes in the container at each stage of the table grape cold chain from origin country to the destination country.

The remainder of this section discusses the distribution of the fruit pulp and ambient temperatures over the entire export cold chain, together with the number and duration of temperature breaks. This indicates the locations and severity of the breaks. This is followed by logit analysis of the temperature variation by vertical position of sensors in the pallet, as well as by horizontal position of pallets in the container. The section concludes with summary results for all the table grape containers.

4.1. Fruit pulp and ambient temperature distribution

The median fruit pulp temperature and median ambient temperature profiles along the export cold chain are presented in Fig. 5. The median temperature was lowest (-0.3 °C for pulp temperature and −0.1 °C for ambient temperature) during the first stage of the export cold chain (packhouse to cold room) as this stage includes FAC in the cold store to cool the grapes until the pulp temperature is −0.5 °C. Although most readings were within acceptable limits and a significant number were within a 50 % range from the median temperature, there were quite a number of extreme values (outliers). This is due to the sensors being inserted while the fruit is packed, before FAC is applied.

By contrast, the highest median temperature readings (1.3 °C and 0.6 °C for pulp and ambient, respectively) occurred during the reefer stack stage. This stage involved the most transitions: container loading at cold store, transportation of container to Cape Town Container Terminal, transfer to stack storage and, finally, loading onto the vessel. The third stage (sea route) was the longest in the export cold chain, with median temperature readings of 0.7 °C and 0 °C for pulp and ambient, respectively. The last and shortest stage, from the destination port to the distribution centre, recorded median temperature readings of 0.2 °C and −0.1 °C for pulp and ambient, respectively. Temperature variation around the median readings was very small for all the stages, except for the outliers in the first stage, as explained above.

From the spike at the end of the first stage, which occurred during the loading of the pallets into the container, the ambient temperature

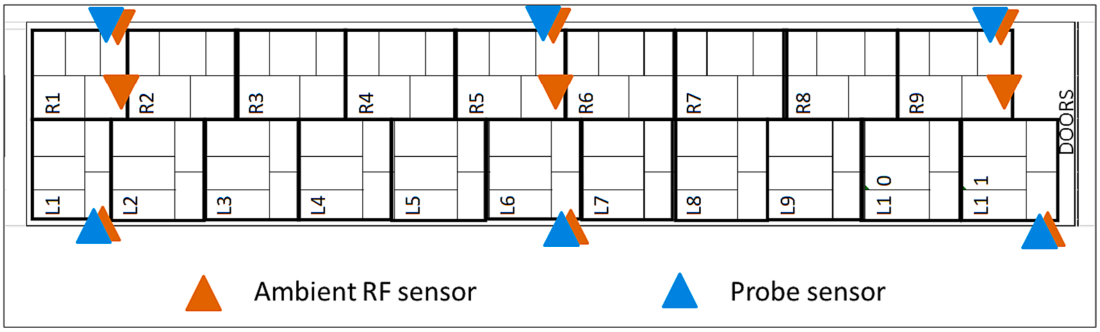

Fig. 2. Top view of container indicating pallet configuration and location of sensors.

a. Position of probe and RF sensors in open punnet in carton

b. Reading on probe sensor in clamshell punnet in carton

c. Pallet R9 – RF and probe sensor in top right-hand corner

d. RF sensors on levels 1, 10 and 18, with large white sticker (wall) next to the yellow sticker on middle level showing side that must face container wall

e. Yellow fluorescent sticker and blue dot (R9) stickers

Fig. 3. Pallet of grapes showing positions of sensors and various stickers.

Table 2
Table grape shipment from South Africa to the UK.

Sensors inserted (packhouse)	9 Mar 2021	Farm 4, South Africa
Depart from cold store to port	18 Mar 2021	Cold Store 3, South Africa
Vessel departs port of origin	29 Mar 2021	Cape Town, South Africa
Vessel arrives at port of destination	12 Apr 2021	London Gateway, UK
Container arrives at destination warehouse	15 Apr 2021	Distribution centre, Bradford, UK
Container unpacked	19 Apr 2021	

readings were slightly lower than the pulp temperature readings, as evident from the graph in Fig. 4 and the box-and-whisker plots in Fig. 5. This may be due to the inability of the container to re-cool the grapes pulp temperature to 0 °C once the temperature had increased.

4.2. Number and duration of temperature breaks

A sensor-level temperature break refers to a temperature break for an individual sensor. A container-level temperature break refers to a continuous period where two or more sensors in a container recorded temperature breaks. As a break can span more than one stage, it is associated with the stage in which it first occurred.

Fig. 6 shows the number and durations of sensor temperature breaks for each category (hot and cold breaks for ambient and pulp sensors) per stage of the cold chain.

More detailed information about container temperature breaks, namely the duration of the break, percentage of sensors that registered the break, maximum and minimum temperatures recorded, and the start and end date and time are provided in Table A.2 in Appendix A. This information helps to interpret the severity of the breaks. As there were 21 RF sensors and six probe sensors measuring ambient and pulp temperatures, respectively, in the container, numerous sensors could register a temperature break at the same time. When two or more sensors registered a break simultaneously, it was counted as a single container break. Fig. 7 displays the same information at container level. All spikes of less than 90 min were filtered out in these tables and graphs.

4.3. Analysis of temperature variation by location of temperature recording

The logit model was used to investigate whether the location of the sensor within the pallet (bottom, middle or top layer) has an impact on the likelihood of a temperature break being registered by the sensor. It was also used to determine whether the location of the pallet within the container (closed end, middle or door end) has an impact on the likelihood of a temperature break being registered by sensors in the pallets.

4.3.1. Temperature variation by location of temperature recording in the pallet

The aim of the analysis was to investigate if there is a significant difference between the ambient temperature readings recorded at the three different locations in a pallet (bottom, middle and top) facing the wall of the container. The ambient temperature profiles during the reefer stack, sea route and distribution centre stages for the sensors in pallet R1 (close to the refrigeration unit) and pallet *L*11 (close to the doors) are presented graphically in Fig. 8. The packhouse to cold store has been excluded as it includes the period before the pallets are cooled to −0.5 °C and before they are loaded into the container.

In pallet R1 the bottom sensor registered cold temperature spikes and breaks whereas the top sensor registered warm temperature spikes and breaks. The cold breaks can be explained by the bottom sensor being close to the cold air vents of the refrigeration unit while the top sensor is close to the warmer air returning to the refrigeration unit as explained in section 2.1. The warm breaks occurred when the pallets were loaded into the container at the start of the reefer stack phase, when the container was unplugged from the reefer stack to be loaded onto the vessel and when the container was offloaded from the vessel in the destination port.

The temperature profiles for pallet L11 are warmer than for pallet R1 with the middle sensor registering the warmest temperatures. The warmer profiles can be explained by the pallet being next to the door at the furthest point from the refrigeration unit. Getahun et al. (2017) established that the air flow velocity is the lowest in the middle of pallets L9, L10 and L11, which could explain the warmer temperatures in the middle of the pallet.

To effectively investigate the relationship between the ambient temperature readings recorded at the three different locations in a pallet

Table 3
Table grape cold-chain stages.

Section	Description
Stage 1: Packhouse to cold store	
Packhouse	Table grapes were either packed in 4.5 kg cartons (in paper bags) or in 9 kg cartons (in punnets) and then palletised. (Temperature sensors were inserted into some cartons in the course of building the pallets)
Cold store	Pallets were delivered by truck to a cold store where FAC was applied, and then shifted by forklift to a cold room.
Stage 2: Reefer stack	
Container loading	Pallets were moved by forklift from the cold room to the staging area and loaded into a container.
Trucking to port of export	Began at the time of containers being weighed at the cold store and ended just before entering the Cape Town Container Terminal (CTCT) for export.
Port of export	Started at the time of entering the CTCT and concluded when the container was loaded onto the vessel. It included the period in the container stacks.
Stage 3: Sea route	
On board vessel at port of export	Started after the container had been loaded onto the vessel until just before its "Actual Time of Departure" (ATD).
Sea-leg of journey	Covers the vessel's ATD up to "Actual Time of Arrival" (ATA) at the destination port.
Aboard vessel at port of import	Started after vessel arrived at the port of destination up to just before the container was offloaded.
Port of import	From time of offloading container from vessel up to being loaded onto a truck just before leaving the destination port.
Stage 4: Distribution centre	
Trucking to cold store	Began at the time the container was loaded on a truck leaving the destination port until the arrival time at the retailer's cold-store.
Cold-store wait	The waiting time from the container's arrival time at the retailer's cold store until just before it is attached to a loading dock.
Container unloaded and cold-store intake	Began at the time container was attached to loading dock and pallets were unloaded until the sensors had been retrieved from the pallets.

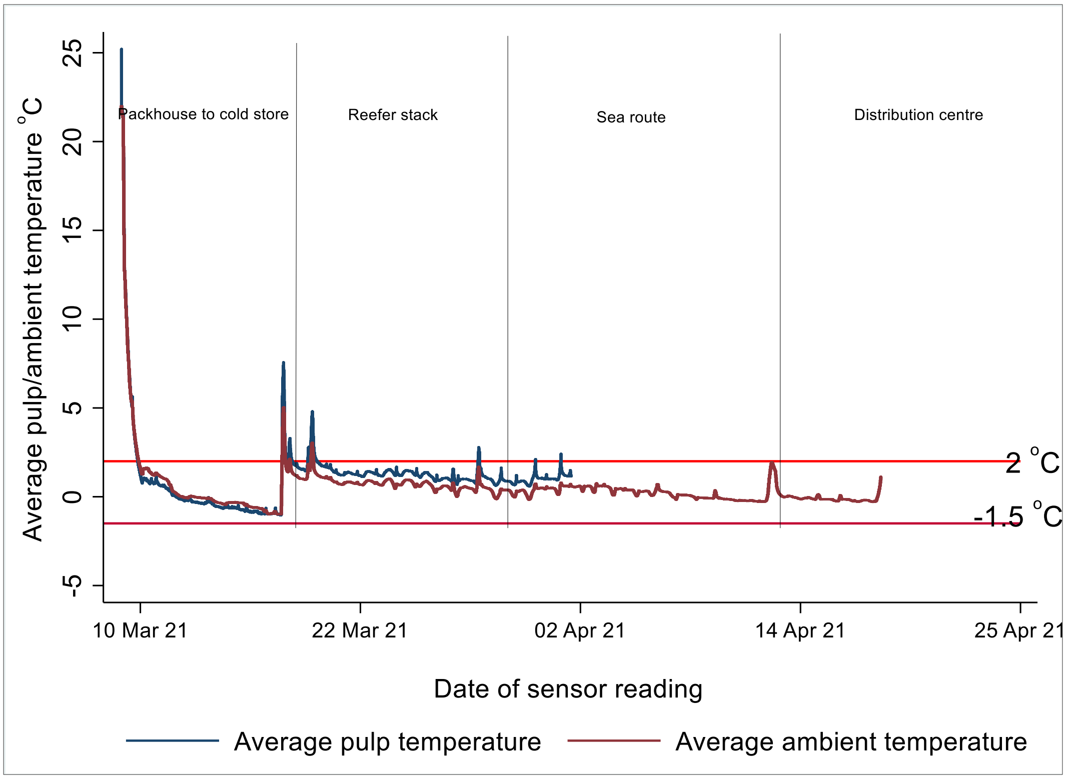

Fig. 4. Average table grape pulp and ambient temperature profile from South Africa to the UK.

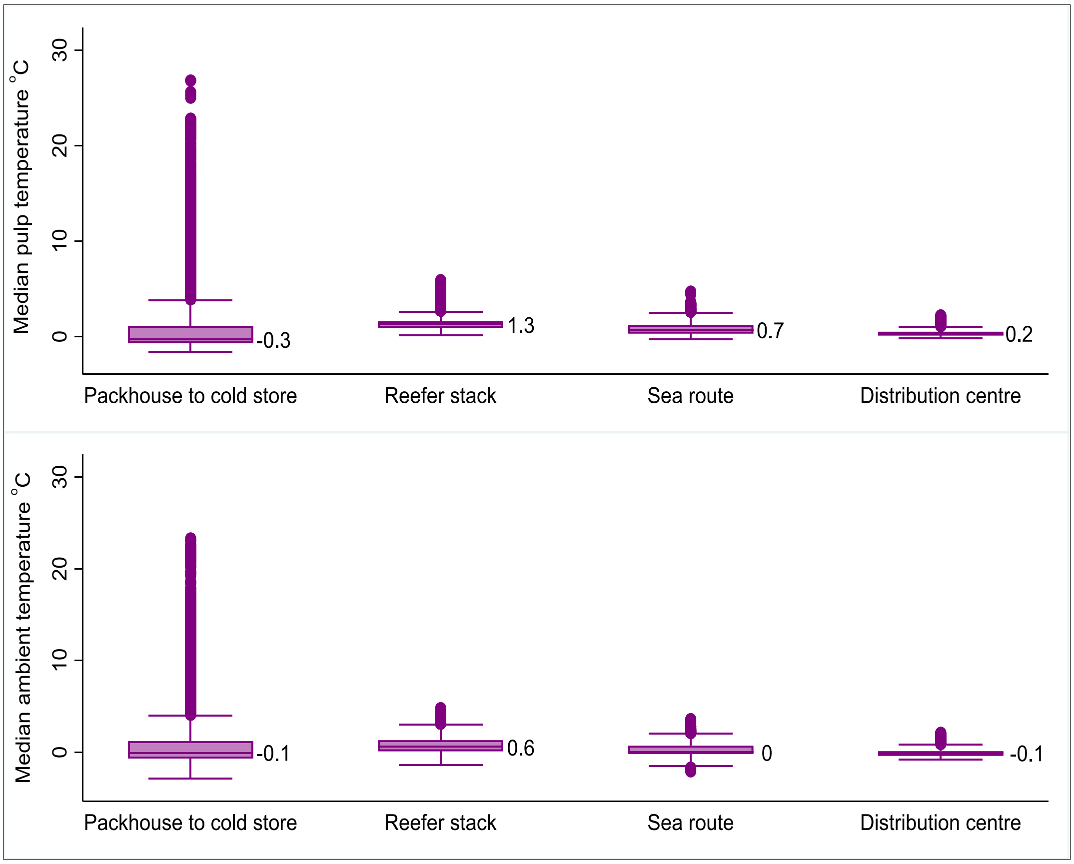

Fig. 5. Fruit pulp and ambient temperature distributions.

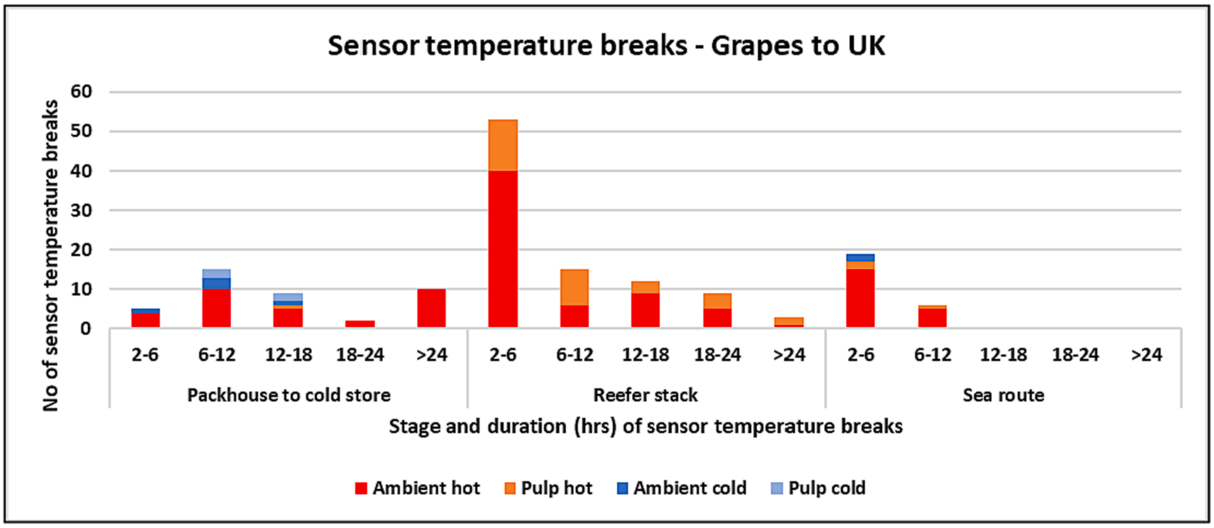

Fig. 6. Sensor temperature breaks and duration per stage.

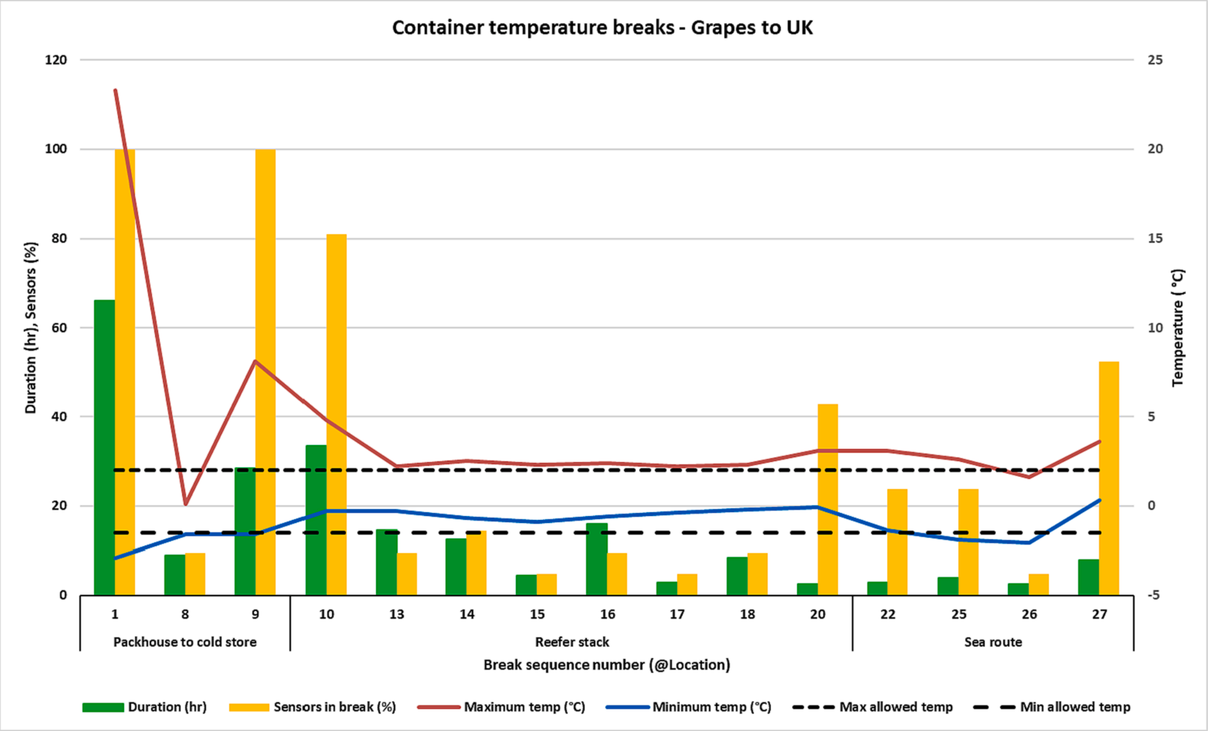

Fig. 7. Duration of container pulp and ambient temperature breaks per stage of the export cold chain (hours).

(bottom, middle and top) facing the wall of the container, the logit model estimated using STATA software was specified as follows:

logit BinaryAmbientTemp TopPosition MiddlePosition, robust

where:

logit=the logit regression model estimation command;

BinaryAmbientTemp = dependent variable for ambient temperature that takes on values that are dichotomous in nature (0, 1), that is, {whether or not ambient temperature rises above 2 °C or drops below −1.5 °C for a period of 90 min or more};

TopPosition = independent dummy variable for the sensors located in the top position of the pallet;

MiddlePosition = independent dummy variable for the sensors located in the middle position of the pallet;

robust = the robust standard errors reported by model.

The bottom position was used as reference point. The results of the logit analysis for the location of the RF sensors in the pallet are shown in Table 4.

Table 4 reports the coefficients and robust standard errors (in brackets) of the estimates of the model. However, the odds ratio is not reported as it is an alternative way of presenting the coefficient log odds estimates. From the table, the estimates show that relative to the bottom sensor position, the log odds of the temperature profile falling outside the acceptable limits (against temperature profile not falling outside the acceptable limits) increases by a magnitude of 0.339 for the top sensors and 0.684 for the middle sensors. Therefore, a temperature break is most likely to be registered by a sensor in the middle of the pallet, followed by

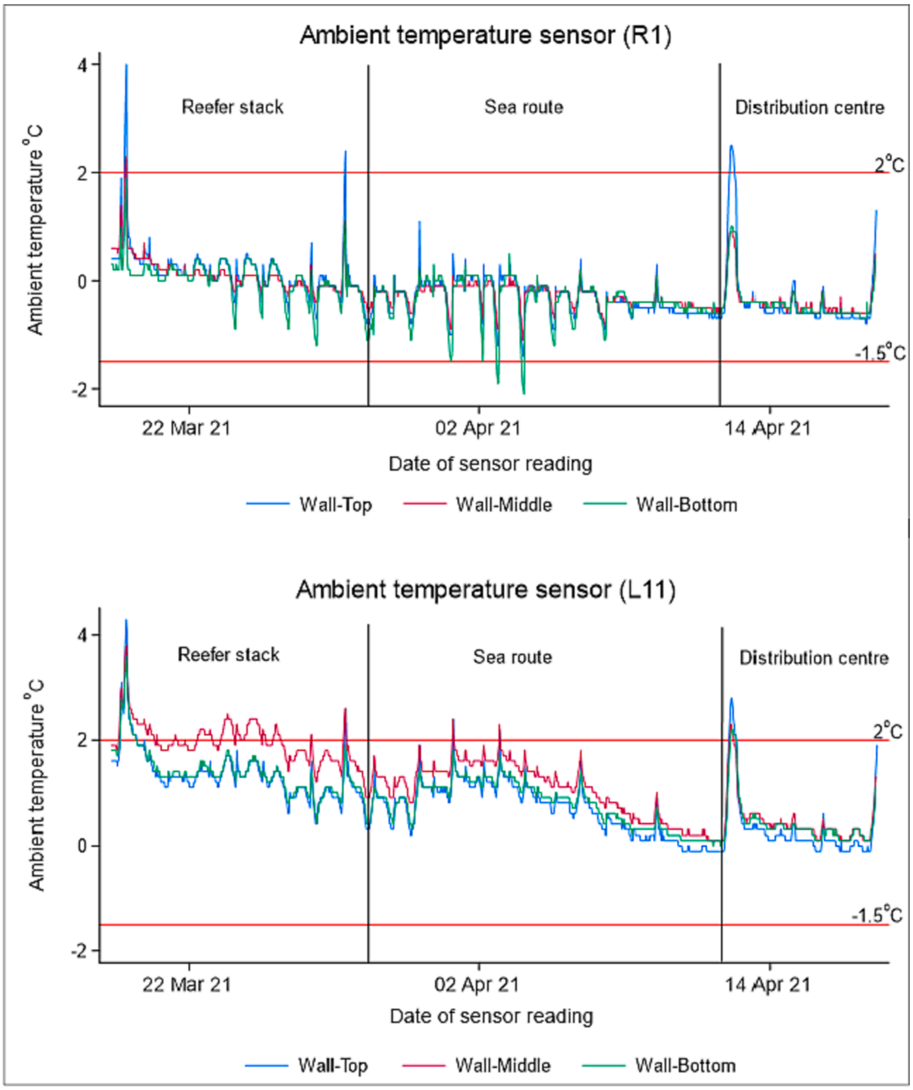

Fig. 8. Graphs of ambient temperature profile by height of sensor for pallets R1 and L11.

Table 4
Logit model of ambient temperature by location of sensors in pallet.

	(RF)
Variables	**Probability of 2 °C < Temperature < -1.5 °C**
Position of sensor	
Top position	0.339***
	(0.0574)
Middle position	0.684***
	(0.0533)
Constant	−3.220***
	(0.0396)
Observations	40 320

Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

a sensor at the top of the pallet.

In terms of the validation test in Table 5, the Hosmer-Lemeshow test value of 0 (p-value > 0.05) means there is not enough evidence to conclude the model is a poor fit. The discriminatory accuracy of the ROC diagnostic test is measured by its ability to correctly classify known normal and abnormal subjects. The AUC value of approximately 0.6 in Table 5 and Fig. 9 suggests that the diagnostic test has some discriminatory ability, that is, the model is capable of differentiating between sensor temperature profiles exhibiting temperature breaks and those not exhibiting temperature breaks.

Table 5
Validation test for logit model.

Hosmer Lemeshow goodness of fit test estat gof, group (10)	Number of groups = 3 Hosmer–Lemeshow chi2(1) = 0.00 Prob > chi2 = 1.0000
ROC Curve	Area under ROC curve = 0.5775

According to the AIC and BIC results in Table 6 for the logit and probit models, there is no evidence that a probit model is a better fit for the data.

4.3.2. *Temperature variation by location of pallet in the container*

The aim was to investigate whether there is a difference between temperatures recorded at different pallet locations in the container. Two separate model specifications were required to accommodate the two types of sensors in the same container.

The logit model for the RF (ambient) sensors was specified as follows:

logit binaryAmbientTemp TopPosition MiddlePosition RHS1 RHS5 RHS9

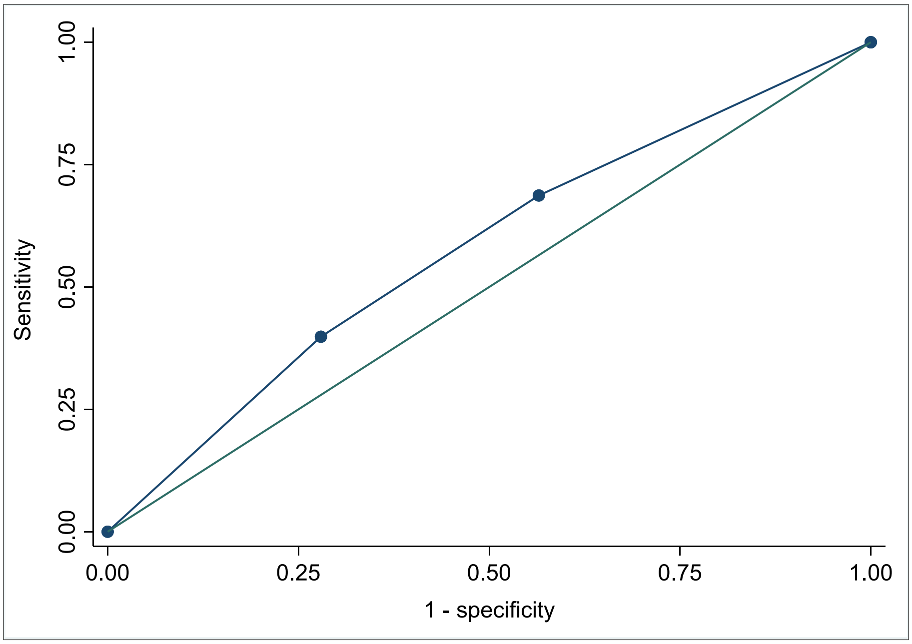

Fig. 9. ROC curve and AUC for the ambient temperature logit model.

Table 6
AIC and BIC for logit and probit models.

Logit model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
.	40,320	−8310.47	−8227.59	3	16461.18	16486.99
Probit model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
.	40,320	−8310.47	−8227.59	3	16461.18	16486.99

Table 7
Logit model of ambient temperature by height of sensor and pallet location.

	(RF)	**(Probe)**
Variables	**Probability of 2 °C < Temperature < − 1.5 °C**	**Probability of 2 °C < Temperature < − 1.5 °C**
Position of sensor		
Top position	0.356***	
	(0.0587)	
Middle position	0.706***	
	(0.0543)	
Pallet position and number		
palletnoR1	−0.402***	−0.160**
	(0.0692)	(0.0630)
palletnoR5	−1.566***	−0.0527
	(0.0983)	(0.0614)
palletnoR9	0.0639	0.462***
	(0.0630)	(0.0554)
palletnoL1	−1.285***	−0.553***
	(0.0961)	(0.0700)
palletnoL6	−0.646***	0.120**
	(0.0781)	(0.0591)
Constant	−2.750***	−2.951***
	(0.0599)	(0.0429)
Observations	40,320	69,066

Robust standard errors in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

LHS1 LHS6, robust

where:

logit = logit regression model estimation command;

binaryAmbientTemp = dependent variable for ambient temperature that takes on values that are dichotomous in nature (0, 1), that is, {whether or not ambient temperature rises above 2 °C or drops below −1.5 °C for a period of 90 min or more};

TopPosition = independent dummy variable for the sensors located in the top position of the pallet;

MiddlePosition = independent dummy variable for the sensors located in the middle position of pallet;

RHS1, RHS5 and RHS9 = independent dummy variables for pallets R1, R5 and R9, respectively. These pallets are located on the right hand side of the container when looking into container from the doors, as shown in Fig. 2;

LHS1 and LH6 = independent dummy variables for pallets L1 and L6, respectively. These pallets are located on the left hand side of the container when looking into container from the doors, as shown in Fig. 2;

robust = the robust standard errors reported by model.

The logit model for the probe (pulp) sensors was specified as follows:

logit binaryProbeTemp RHS1 RHS5 RHS9 LHS1 LHS6, robust

where:

binaryProbeTemp = the dependent variable (pulp temperature) that takes on values that are dichotomous in nature (0, 1), that is, {whether or not ambient temperature rises above 2 °C or drops below −1.5 °C for a period of 90 min or more};

and the independent variables are as previously defined.

Pallet L11 (on the left hand side at the door) was used as reference point for both models. Unlike the RF sensors, there was only one probe sensor per pallet (inserted at the top) so location dummies were not included in the model due to collinearity. Table 8 shows the results of the two models.

The results in Table 7 indicate that, relative to pallet L11, the log odds of temperature profiles of the ambient and pulp sensors in pallets R1 and L1 (closed end of the container, near the cooling unit) experiencing temperature breaks (against not experiencing temperature

Table 8
Validation test for logit model.

	RF	Probe
Hosmer Lemeshow goodness of fit testestat gof, group (10)	Number of groups = 8 Hosmer–Lemeshow chi2 (4) = 69.05 Prob > chi2 = 0.0000	Number of groups = 6 Hosmer–Lemeshow chi2 (4) = 0.00 Prob > chi2 = 1.0000
ROC Curve	Area under ROC curve = 0.6703	Area under ROC curve = 0.5812

breaks) are very low by virtue of where they are located in the container. For pallet R9 (at the door of the container) the log odds of the ambient and pulp sensor temperature profiles experiencing temperature breaks are high though only statistically significant for the pulp sensor. The result for pallets R5 and L6 (middle of the container) are not conclusive. The ambient sensors are less likely to record temperature breaks. The pulp sensor in R5 is also slightly less likely to record temperature breaks, but the result is not statistically significant, whereas the pulp sensor in L6 is more likely to record temperature breaks.

Table 9
AIC and BIC for logit model and probit model.

Logit model	N	ll(null)	ll(model)	df	AIC	BIC
RF	40,320	−8310.469	−7926.262	8	15868.52	15937.36
Probe	69,066	−13748.02	−13600.77	6	27213.53	27268.39
Probit model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
RF	40,320	−8310.469	−7932.665	8	15881.33	15950.17
Probe	69,066	−13748.02	−13600.77	6	27213.53	27268.39

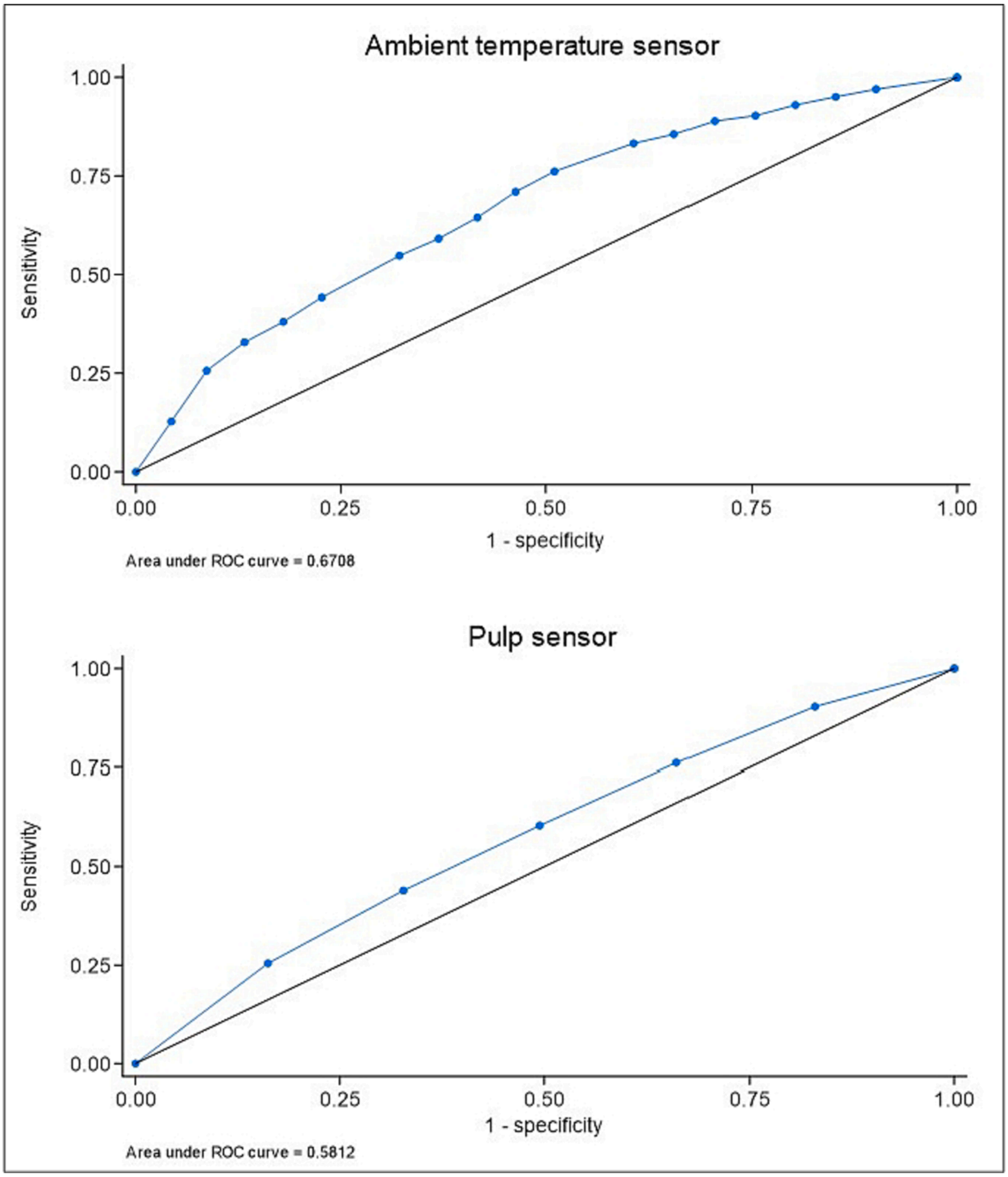

Fig. 10. ROC curve and AUC for the ambient and pulp temperature sensor logit models.

The validation test results in Table 8 indicate that the Hosmer-Lemeshow test values give contrasting results. Whereas the ambient temperature logit model results seem to suggest a poor fit for the model, the pulp logit model results suggest the model is a good fit for the data. However, for the diagnostic test results the AUC values of approximately 0.7 (ambient sensor) and approximately 0.6 (pulp sensor) in Table 8 and Fig. 10 suggest the model is capable of differentiating between ambient and pulp sensor temperature profiles exhibiting temperature breaks and those not exhibiting temperature breaks.

According to the AIC and BIC results for the logit and probit models in Table 9, there is enough evidence to show that the probit models are not a better fit for the data than the logit models.

5. Conclusions and recommendations

The findings indicated that the most severe temperature breaks in terms of maximum temperatures logged occur during the reefer stack stage, i.e. the period from when the pallets are moved from cold room to staging area to be loaded into the reefer container until the container is connected to a power supply at the reefer stack inside the port. Significant temperature breaks were recorded even when temperature-controlled airlock loading bays were used.

It is recommended that further trials be done with GPS-enabled temperature sensors to determine the maximum temperatures recorded during loading as well as the progression of the temperature breaks while the container is without cooling during transportation from the cold store to the departure port. It would be possible to determine the exact arrival time of the container at the port and how much time elapses until it is connected to a power supply. Once these results are available, an analysis of the costs versus the benefits should be undertaken for the use of a genset to keep the container refrigerated during loading and transportation to the port. This should eliminate the most severe temperature breaks.

In addition, less severe temperature breaks often occur between the times when containers are unplugged from the reefer stack and when they are plugged into a power supply on board the vessel. These breaks could be minimised by streamlining operations at the container terminal and continuously educating staff about the importance of managing the cold chain properly. It is crucial all important players in fruit export cold chains understand the detrimental implications of temperature breaks and the role each of them play in maintaining the cold chain.

The use of advanced analytical techniques such as the logit model have helped to shed more light on the association between the location of sensors in a pallet, the position of pallets in a container and the magnitude or severity of temperature breaks. The analysis showed, for instance, that although the likelihood is very high that sensors located in the middle and top layer of the pallet will record temperature breaks (relative to sensors located at the bottom of the pallet), the magnitude is higher for the middle sensors. This implies that hotspots are more likely to form in the upper half of the container than near the floor. Similarly, the logit results confirmed the findings from the plots and heat maps that temperature breaks have a higher likelihood to occur in pallets located at the door end of the container than those located at the closed end near the refrigeration unit. This indicates that hotspots tend to occur near the doors of the container. In practical terms, this provides further evidence for quality control officials to focus on these issues in the export cold chain to prevent loss of quality and extend the shelf-life of table grapes.

In conclusion, the implication for the table grape industry and decision makers (like fruit industry bodies) is to put measures in place to ascertain the feasibility of incorporating independent quality reports like the one from this study into their operations. In addition, the grape exporters should consider using real-time GPS-loggers for the export cold chain, which will allow them to proactively respond to temperature breaks along the cold chain. Similarly, the port authorities and the government should work hand-in-hand with the industry to improve upon port facilities to ensure the ports are equipped with the necessary infrastructure, equipment and skillset required to ensure that the South African table grape industry remains competitive in the global market.

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CRediT authorship contribution statement

Leila Louise Goedhals-Gerber: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Esbeth van Dyk:** Investigation, Methodology, Writing – original draft, Writing – review & editing. **Roland Yawo Getor:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Barrie Louw:** Project administration, Writing – original draft. **Nishikant Mishra:** Writing – review & editing.

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.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2024.101054.

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