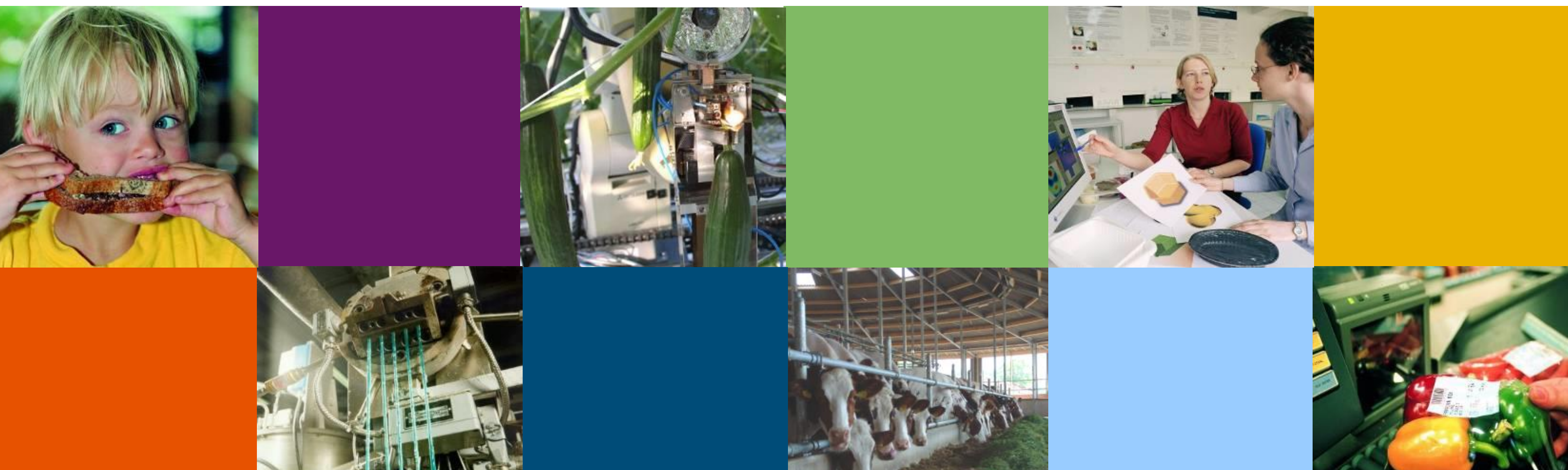
FOOD & BIOBASED RESEARCH
WAGENINGEN UR

A floor cover to improve temperature distribution and quality preservation in maritime refrigerated container transport of grapes

GreenCHAINge WP1 – Table Grapes

Leo Lukasse, Manon Mensink, Edo Wissink
April 2017

Report no. 1733



Colophon

Title	A floor cover to improve temperature distribution and quality preservation in maritime refrigerated container transport of grapes
Author(s)	Leo Lukasse, Manon Mensink, Edo Wissink
Number	1733
ISBN-number	978-94-6343-660-1
Doi	10.18174/420926
Date of publication	April 2017
Version	1.0
Confidentiality	No
Approved by	Ir. Janneke de Kramer
Review	Internal
Name reviewer	Eelke Westra
Sponsor	Foundation TKI Horticulture
Client	Bakker Barendrecht, VEZET, Albert Heijn, Maersk Line

Wageningen Food & Biobased Research
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480 084
E-mail: info.fbr@wur.nl
Internet: www.wageningenur.nl/en/fbr

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system of any nature, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publisher. The publisher does not accept any liability for inaccuracies in this report.

Abstract

Like many other fruits, table grapes depend on accurate temperature management during transport in maritime refrigerated containers. Ideally the temperature inside the container is equal to set point in every location in the container. Unfortunately door-end temperatures are always higher due to poor air flow distribution. In climate chamber tests Lukasse & Staal (2016a and 2016b) investigated the effect of covering sections of the container's T-bar floor. The best T-bar floor cover found in that study was a trapezoid-shape floor cover. The aim of this study is to assess the effect of that trapezoid-shape T-bar floor cover on temperature and fruit quality in commercial reefer container transports of grapes.

A field experiment was done in a commercial container shipment of six standard 40 ft. HC reefer containers travelling from South Africa to The Netherlands taking 24 days. The three test containers contained a T-bar floor cover. The three reference containers did not contain the T-bar floor cover. All other parameters were, to the extent possible, the same for all containers. In 31 locations air temperature between the fruit was logged at an interval of 10 min. with an accuracy of approx. ± 0.1 °C. 15 Trays, evenly distributed in a vertical plane on the container's longitudinal centre line, were weighed at origin and at destination. At destination the fruit quality of these 15 trays was analysed.

A clear positive effect on temperature was observed. The floor cover reduces the average difference between warmest and coldest temperature in the trays by approx. 30%. An effect on grape quality could not be assessed.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

Content

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

1 Introduction

Like many other fruits, table grapes depend on accurate temperature management. Ideally in reefer container shipments of grapes the temperature inside the container is equal to set point in every location in the container. Unfortunately door-end temperatures are always higher. See Fig. 1 as an example.

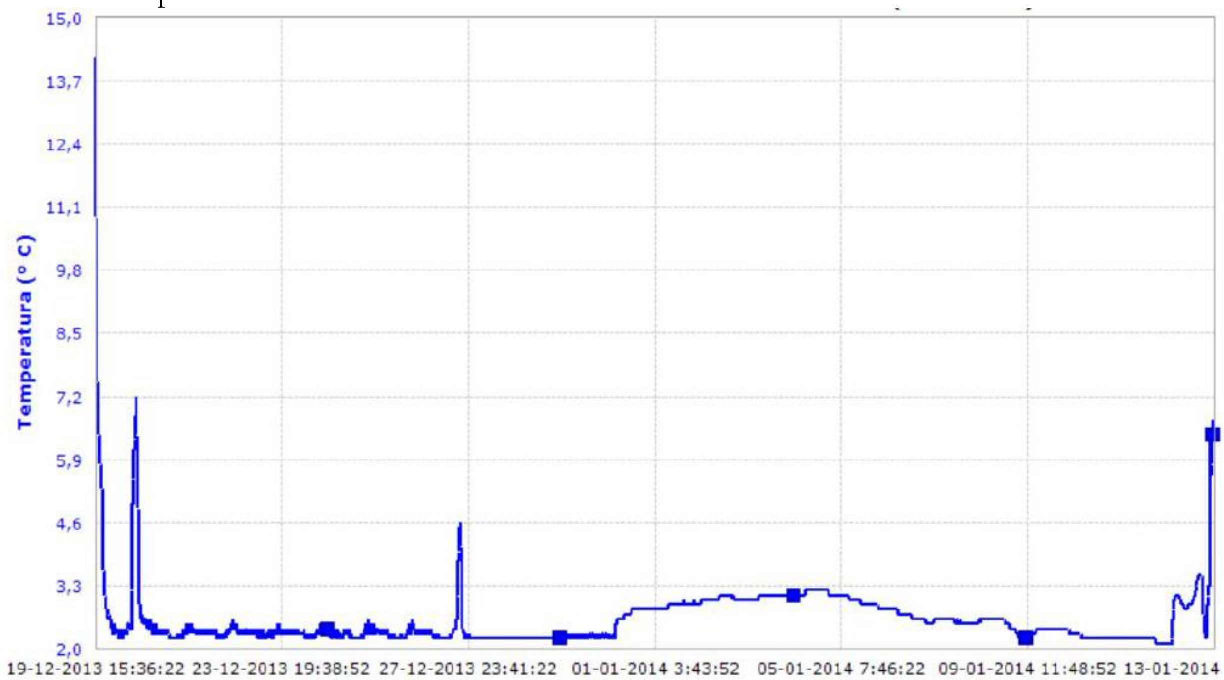


Fig. 1, an example of door-end temperature registration collected in a grape shipment at a +0.5 °C set point.

In earlier work Lukasse & Staal (2016a) found that T-bar floor covers can indeed help to guide more air towards the door-end and hence reduce door-end temperatures. The best T-bar floor cover shape found in that study is very similar to the one presented in Fig. 7. Lukasse & Staal (2016a and 2016b) recommended to assess the effectiveness of the T-bar floor cover in a large scale field experiment. That field experiment is the topic of this study.

The aim is to experimentally assess the effect of using the T-bar floor cover during real reefer container transport of grapes. More specific research questions are:

1. What's the effect of the floor cover on temperature gradients?
2. What's the effect of the floor cover on grape quality at arrival?

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

2 Theory

2.1 Air flow distribution in reefer containers

As already explained in Lukasse & Staal (2016a) for climate control in contained spaces conditioned air needs to be guided to the place where it is needed. This is typically done by air ducts. For example virtually every office building has these air ducts, usually hidden behind the ceilings. In the design of air ducts the diameter of the ducts is tuned to air flow rates: wide ducts close to the air conditioning unit, and small ducts delivering the air to the most distant office space. The relatively high air flow resistance of the air duct outlets, as compared to the resistance inside the ducts, helps to achieve a relatively even air distribution throughout the office building. Reefer containers have a T-floor. The T-floor exists of 35 longitudinal T-bars extending over the complete length of the container's cargo space (see Fig. 2). T-bars are the air ducts of reefer containers, but their design is rudimentary: the cross section is the same over the complete length, and the air flow resistance of the air outlet at the top of the T-bars is very low. Hence most air escapes from the ducts before reaching the container door-end if no further measures are taken. Therefore dedicated T-bar floor covers or cargo stowage patterns, closing off the right areas of the T-bar top openings, are a means to guide air to where it is needed and thus improve temperature management. That's why the use of fillers, a.k.a. dunnage is recommended (see e.g. anonymous, no year; de Haan, no year; Montsma et al., 2011). Also covering parts of the floor has been reported (Cronje et al., 2015; Defraeye et al., 2016; Norrefeldt, 2015b; Elíasson et al., 2013). Lawton (1994; 1999) presents an L-shaped board placed against / on top of the door-end pallets with the aim to exploit the fact that air inside T-bars warms more than in centre T-bars. The test results reported in Lawton (1999) concern a hand-stowed cargo, while there is no mentioning of palletized cargo. The system is especially meant for tight stows. For loads of trays, specifically facilitating horizontal air flow, even more complex air guidance systems have been proposed (Dodd & Worthington-Smith, 2006).

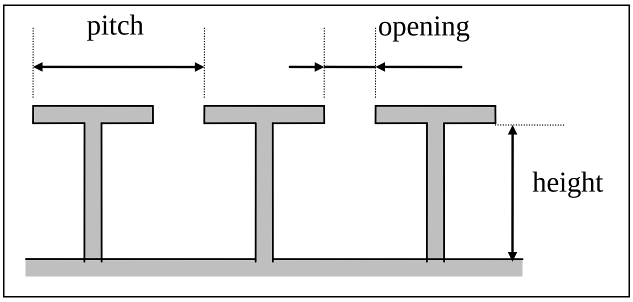


Fig. 2, schematic cross section of a T-bar floor section. Standard dimensions in 40ft HC reefers: height = 60 mm, pitch = 63.5 mm, opening = 35 mm.

Lukasse & Staal (2016a and 21016b) were the first to propose a one-piece trapezoid shape floor cover, covering the major part of the floor. They report a nearly 50% reduction of cargo temperature differences, measured in climate chamber tests. The subject of this study is to assess the effectiveness of that floor cover in real transports.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

2.2 Key performance indicators

In an experimental study on temperature distribution in reefer containers lots of data need to be evaluated, and somehow condensed to one or a few simple measures. In climate chamber tests one would typically create a pure steady state. That is not possible in field experiments. Therefore a practical approach needs to be taken.

Table 1 lists the key performance indicators used to evaluate the data collected by the experiment's 31 loggers per container, which are more or less evenly distributed throughout the container load. The KPIs will be explained in the following paragraphs.

Table 1, key performance indicators used to evaluate the results

Name	Description
mean temp.	average over all loggers and all sampling instants
SD temp.	standard deviation over all loggers and all sampling instants
(warmest-coldest), all trip	Warmest time-averaged sensor minus coldest time-averaged sensor in a container. The time-average is taken over the whole trip.
(warmest-coldest), hot ambient	Warmest time-averaged sensor minus coldest time-averaged sensor in a container. The time-average is taken over the 48 hours period where ambient temperature was highest.
coldest sensor ID, hot ambient	Location of the sensor which recorded the coldest time-averaged temperature during the 48 hours period where ambient temperature was lowest.
warmest sensor ID, hot ambient	Location of the sensor which recorded the warmest time-averaged temperature during the 48 hours period where ambient temperature was highest.

'Mean temp.' is just one number, being the average over the temperatures recorded by all loggers over all sampling instants from stuffing till unstuffing:

$$mean\ temp. = \frac{\sum_{ti=1}^{Ni}\sum_{s=1}^{Si} T(s,ti)}{Ni*Si} \quad [°C] \quad (1)$$

with

T(s,ti) = the temperature recorded by loggers on time instant ti

Si = total number of loggers per container (= 31).

Ni = total number of sampling instants from stuffing till unstuffing

Reefer containers set at -0.5 °C control the supply air temperature measured by the unit's supply air temperature sensor to set point. A low mean temperature is therefore indicative of more homogeneous temperatures. However the unit's supply air temperature sensor is not perfect. A sensor offset of e.g. +0.1 °C reduces the temperature at all locations in the container by 0.1 °C, thus reducing the mean temperature, without affecting temperature homogeneity. Hence solely analysing mean temperature is not good enough.

Standard deviation does not suffer the above described weakness. 'SD temp.' is the standard deviation of the temperature readings recorded by all loggers over all sampling instants from stuffing till unstuffing:

$$SD\ temp. = \sqrt{\frac{1}{Ni*Si-1}\sum_{ti=1}^{Ni}\sum_{s=1}^{Si}(T(s,ti) - mean\ temp.)^2} \quad [°C] \quad (2)$$

In general, a low standard deviation indicates that the data points tend to be close to the mean value of the data set. Assuming normally distributed temperature readings, 68% of the readings are within the range mean temp. ± SD temp. Hence, the lower SD temp. the more homogeneous the temperatures within the container.

Another criterion, insensitive to possible unit sensor faults, is the difference between the warmest and the coldest logger. '(Warmest-coldest), all trip' is the warmest time-averaged logger minus coldest time-averaged logger in a container, where the time-average is taken over the whole trip:

$$(warmest - coldest)_{all\ trip} = \max_s\left(\frac{\sum_{ti=1}^{Ni} T(s,ti)}{Ni}\right) - \min_s\left(\frac{\sum_{ti=1}^{Ni} T(s,ti)}{Ni}\right) \quad [°C] \quad (3)$$

When ambient temperature is highest gradients inside the container tend to be highest. Therefore it can be informative to analyse the difference between the warmest and the coldest logger specifically during the period where ambient temperature was highest, this is done in '(warmest-coldest), hot ambient':

$$(warmest - coldest)_{hot\ ambient} = \max_s\left(\frac{\sum_{ti=ths}^{the} T(s,ti)}{the-ths+1}\right) - \min_s\left(\frac{\sum_{ti=ths}^{the} T(s,ti)}{the-ths+1}\right) \quad [°C] \quad (4)$$

where

ths = time instant defining the start of the period of hot ambient.

the = time instant defining the end of the period of hot ambient.

Finally, it is informative to know the locations of the coldest and the warmest spots. These are given in 'coldest sensor ID, hot ambient' and 'warmest sensor ID, hot ambient':

$$(coldest\ sensor\ ID)_{hot\ ambient} = \underset{s}{\text{argmin}}\left(\frac{\sum_{ti=ths}^{the} T(s,ti)}{the-ths+1}\right) \quad [°C] \quad (5)$$

$$(warmest\ sensor\ ID)_{hot\ ambient} = \underset{s}{\text{argmax}}\left(\frac{\sum_{ti=ths}^{the} T(s,ti)}{the-ths+1}\right) \quad [°C] \quad (6)$$

The analysis is done in the period where ambient is hot, because that's when the gradients are most pronounced.

Apart from the KPI's described in Table 1 some temperature contour plots for cross sections of the containers will be made to visualize temperature gradients throughout the containers at some moments during the trip.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

3 Materials and methods

A field experiment was done in a commercial container shipment of six standard 40 ft. HC reefer containers travelling at the same time in the same corridor. The three test containers contained a T-bar floor cover, the three reference containers did not contain the T-bar cover. All other parameters were as much as possible identical. A known weak link in the air flow circulation in reefer containers is the position of the baffle plate, connecting the refrigeration unit's supply air duct to the entrance of the container's T-bar floor. Therefore during stuffing special attention was paid to this, and it was witnessed that all of them were in the right position, neatly connecting to the T-bar floor. See Fig. 3 as an example.

Fig. 3, baffle plates connect properly to T-bar entrance.

Fig. 4, trial containers waiting to be stuffed.

See Table 2 and Table 3 for detailed specifications of containers and journey.

Table 2, container specifications.

Characteristic	Value
refrigeration unit	manufacturer: Carrier, type: PrimeLine
set temperature	-0.5 °C
fresh air exchange	closed
test containers	container A, B, C (with floor cover)
reference containers	container D, E, F (without floor cover)
manufacturing date	container A, B, C, D, E: 2015 container F: 2009
positions on board	All containers on deck on tier 1, none of them at the outer bay. Hence all of them are shaded from direct sunlight and experience approx. the same ambient temperature.

Table 3, trip details.

Characteristic	Value
date of stuffing	21-01-2017
place of stuffing	Gouda, South Africa
date of loading on vessel	26-01-2017
date of unloading from vessel	13-02-2017
date of unstuffing	14-02-2017
place of unstuffing	Barendrecht, The Netherlands
port of loading	Capetown, South Africa
port of unloading	Rotterdam, The Netherlands

3.1 Packaging and stowage

Each container was stowed with 21 pallets according to the floorplan sketched in Fig. 11. Pallet 19 is a europallet (80 x 120 cm), all other pallets are standard pallets (100 x 120 cm).
The pallets have a forklift pocket of 9 cm high. The total pallet height is 15 cm. Trays are stacked 25 layers high. The height of the pallets stacked with trays is 2.40m. Standard pallets carry five, and the euro pallet four, stacks; resulting in 125, resp. 100, trays per pallet. After every third layer a pallet-size corrugated cardboard sheet with some limited perforations is inserted. The cardboard sheet connects the separate stacks in a cunning way, providing stability to the pallet load. Each pallet is covered with a cardboard pallet hood (Fig. 6).
All grapes are cultivar Thompson Seedless, class 1, of regular berry size.
When filling a tray first one LDPE liner is placed. 11 Punnets with grapes are placed inside the liner. One SO2 pad is placed on top of the punnets, then the liner is folded over the punnets and SO2 pad, and non-hermetically closed with three small adhesive tapes.
The SO2 pads are so-called uvasys dual release pads (www.uvasys.co.za).
Punnets are made of transparent polypropylene, and have dimensions L x W x H = 18.7 x 11.5 x 8.0 cm. Each punnet contains 500 gr. of grapes. Punnets have eight vent holes of ø8mm: four in the bottom and four in the lid. The lid contains 12 evenly distributed vent openings of L x W = 15 x 5 mm. Moreover after closing the lid a 4 mm air slit remains at the two short sides and at one long side.
Liners contain 52 vent openings of ø6mm, evenly distributed over the sides, and the outer areas of top and bottom area folded around the 11 punnets.
Trays are made of corrugated cardboard, and measure L x W x H = 60 x 40 x 9 cm. The bottom of the trays contains four vent openings of ø25mm. The trays have an open top. In the upper end of the long sides the trays have an opening of 33 x 220 mm, allowing for some horizontal air flow (Fig. 6).
The space for vertical air flow through a pallet load is very limited, because vent openings in the bottom of trays are limited in size and number and effectively blocked by the liner on top of it.
The space for horizontal air flow through a pallet load is also limited. The short sides of trays have no vent openings. The long sides of trays have a vent opening, but most of this area is

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

obstructed by punnets folded in the liner. Moreover, the bottom of the next tray ± rests on top of the punnets in a tray. In the experiment layer 12 is assigned as the middle layer. Possibly only the three stacks next to each other, with connected vent openings in the long tray sides, allow for someone-directional horizontal air flow through the pallet load. See Getahun et al. (2017) for possible consequences on temperature gradients.

3.2 T-bar floor cover

The airflow enhancing T-bar floor cover was provided by www.otflow.com. The company manufactures floor covers based on the test results of Lukasse & Staal (2016a and 2016b). For ease of manufacturing the dimensions deviate a little from those of the best floor cover reported in Lukasse & Staal (2016a and 2016b). See Fig. 5 for a floor cover installed in a reefer, and Fig. 7 for a sketch of the floor cover used in this trial, including its dimensions.
Thanks to the trapezoid shape first the wall-side T-bars open up. The further from the unit-end the more side T-bars open up. This favourably stimulates air, leaving the T-bars before the door-end, to flow between the cargo and the wall, where heat enters the container. The air in the centre T-bars can only leave the T-bars near the door-end, and is used for removing heat from the door-end.

Fig. 5, floor cover installed in a reefer container.

Fig. 6, 5 stacks of 25 trays per pallet, and a cardboard pallet hood on top.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

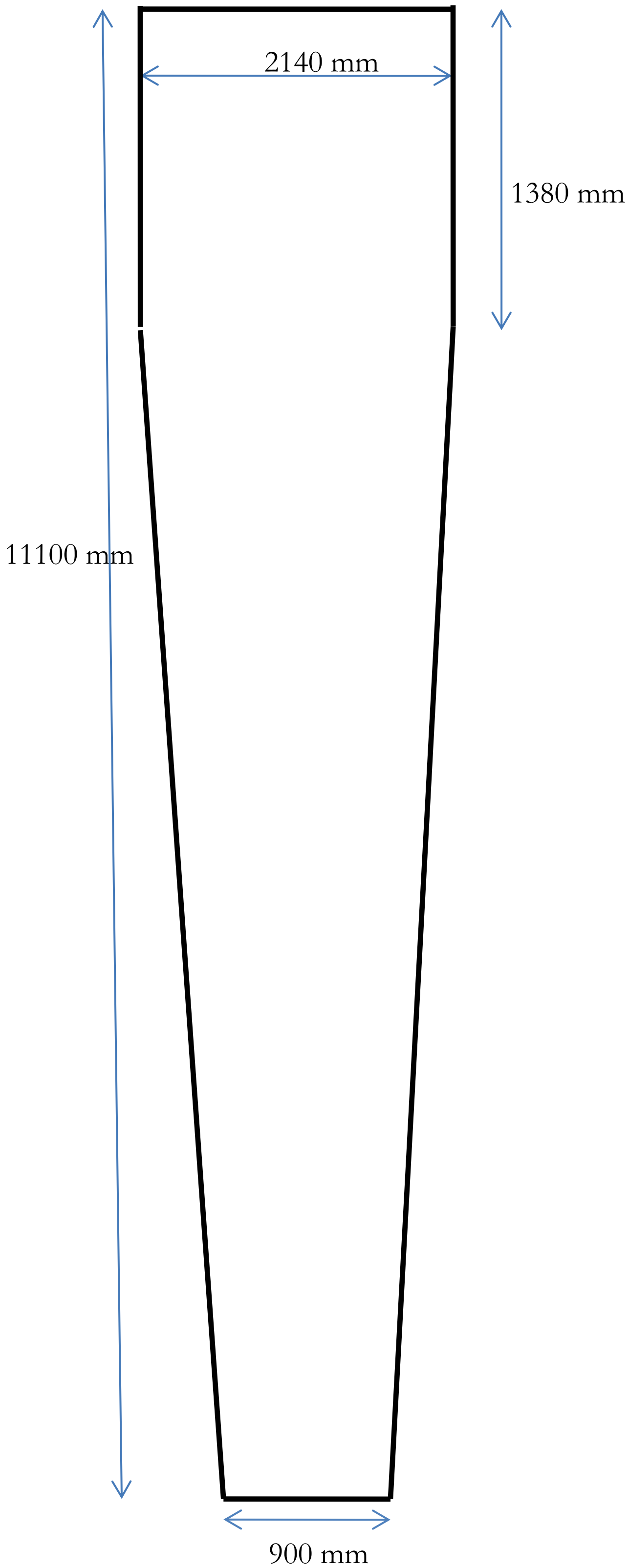


Fig. 7, sketch of floor cover used in the experiment (dimensions in mm). The narrow end is placed at the door-end 580 mm from the end of the T-bar. As a result the 2175 mm wide section at the unit-end covers 2000 mm of T-bar and approx. 325 mm of baffle plate.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

3.3 Measurements and instrumentation

In each container the temperatures were recorded in 31 locations. See Fig. 11 for the exact positions. Fig. 8 depicts one of the temperature loggers used in the trial. The loggers have a 0.1 °C resolution and accuracy better than ± 0.5 °C (manufacturer spec). Temperatures were logged at 10 min. intervals. Loggers were pre-calibrated at 0 °C and 30 °C. During the pre-calibration the loggers were placed in trays with a grated bottom, a calibrated high-accuracy reference sensor was placed between the loggers, and forced air flow was drawn through the trays. The post-calibration was done to just mutually compare the loggers by placing the loggers on a grated shelf in a 2 °C cold room, without forced airflow, and without reference temperature sensor.

Fig. 8, LogTag trix8 temperature logger used in the trial.

Fig. 9, logger pre-calibration set-up.

Fig. 10, loggers during post-calibration

From the 31 trays per container equipped with temperature recorders 15 were selected for quality inspection during stuffing and unstuffing, from here indicated as the Q-trays. See Fig. 11 for the exact positions. It was assumed that the quality at origin was identical for all trays, and therefore the quality inspection was limited to weighing the 15 Q-trays per container. During stuffing the prepared experimental pallets were placed in their designated positions. During unstuffing the temperature loggers were retrieved and for the 15 Q-trays per container the quality was inspected. Quality inspection then existed of weighing and scoring two quality attributes: percentage stem browning, and the number of poor berries. Both quality attributes were scored without opening the punnets. The quality inspector opened the liner, viewed the punnets and estimated the percentage of the visible part of the stems that looked not fresh green. The number of poor berries was scored by counting the poor berries visible in five punnets, arbitrarily selected out of the 11 punnets per tray, without opening the punnets.
All reefer unit datalogs, logging with 60 min. intervals, were downloaded after arrival in the port of destination.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

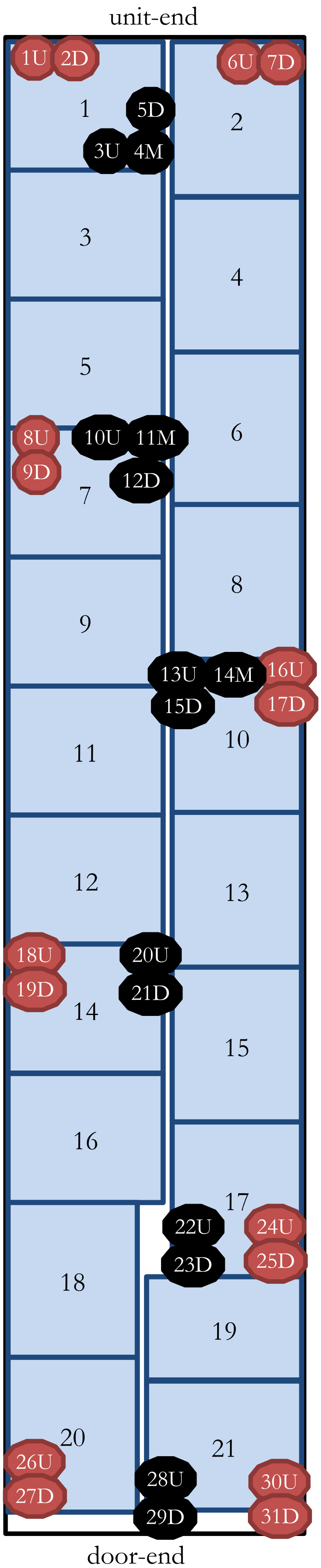


Fig. 11, placement of temperature recorders in all trial containers. Note: Red circles indicate positions of temperature logger numbers, U = Up (top layer), D = Down (bottom layer), M = Middle (layer 12). Black circles indicate positions of temperature logger numbers and those trays are used for quality inspection. In reality e.g. recorder 3, 4, 5 are positioned right above each other, it's just for ease of drawing in the 2D plane that they're drawn beside each other.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

3.4 USDA probes and datalogs

Reefer container units are standard equipped to connect three so-called USDA temperature probes, which can be inserted anywhere in the cargo, and whose readings are then logged in the unit's controller. These probes are routinely used in cold treatment protocols imposed by quarantine authorities of receiving countries. In this trial, though not a cold treatment shipment, in each container three USDA probes were inserted in the locations usually prescribed by quarantine authorities.

Table 4, description of USDA sensor positions. Note: let/right is seen from tuck driver's perspective.

USDA	pallet ID	up/down	left/right	unit/door-end side of pallet
1	1	up	right	unit-end side
2	18	middle	right	door-end side
3	18	middle	left	door-end side

In all containers pallet 18 was positioned such that from the door-end one faces the 40 cm side of a tray at the left (against the wall), and the 60 cm side of a tray at the right (against pallet 19).

 © Wageningen UR Food & Biobased Research, institute within the legal entity Stichting Dienst Landbouwkundig Onderzoek

4 Results

4.1 Information from the datalogs of the refrigeration unit's controllers

The unit datalogs (Fig. 12 - Fig. 17) confirm that all units operated normally. Moreover on first sight the recordings of USDA2 and USDA3 do not show a clear effect of the floor cover. The unit datalogs also record ambient temperature (not shown in Fig. 12 - Fig. 17). The warmest ambient temperatures are recorded between 31-01-2017 and 02-02-2017, day 10 till 12 of the trial. In that period all six units record very similar ambient temperatures, fluctuating between 26 and 35 °C.

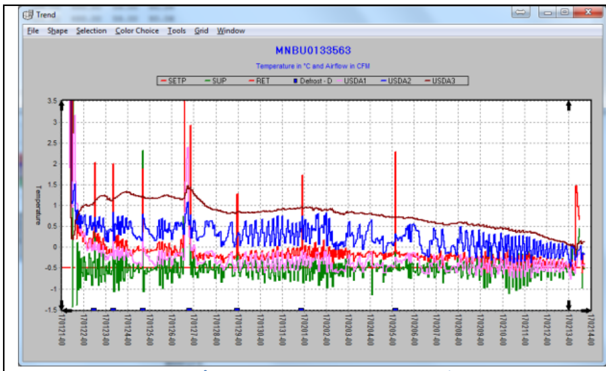


Fig. 12, reefer unit's datalog for container A.

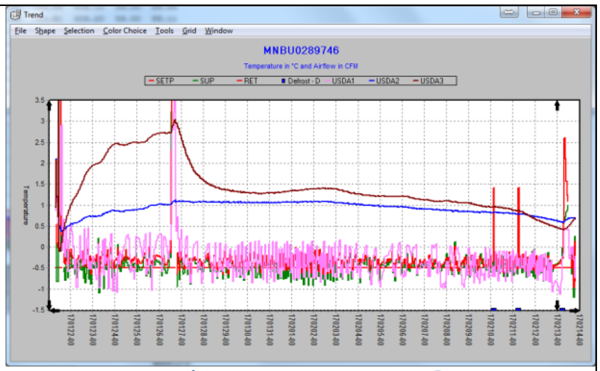


Fig. 13, reefer unit's datalog for container D.

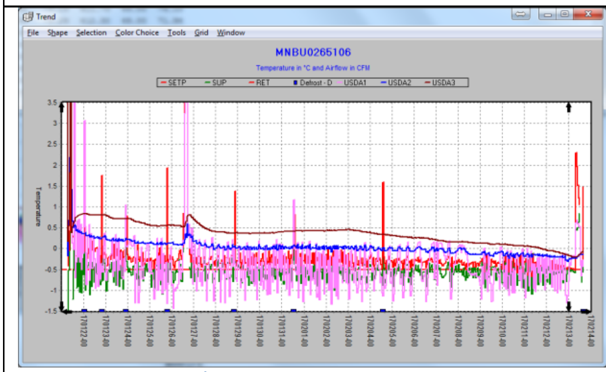


Fig. 14, reefer unit's datalog for container B.

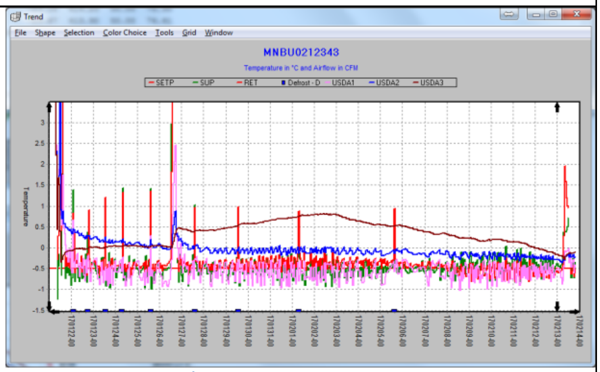


Fig. 15, reefer unit's datalog for container E.

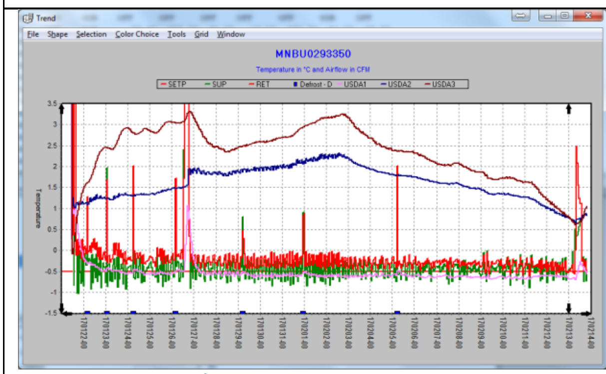


Fig. 16, reefer unit's datalog for container C.

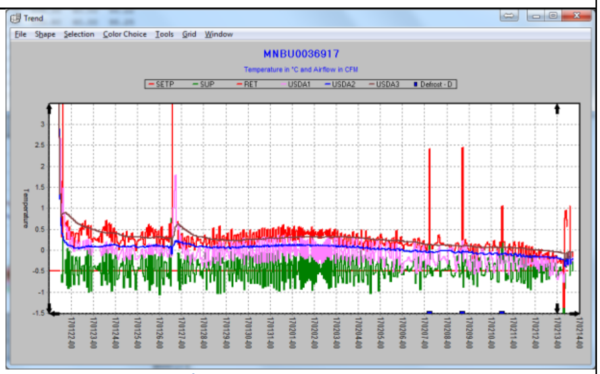


Fig. 17, reefer unit's datalog for container F.

4.2 Temperature logger calibrations

For the pre-calibration results see Fig. 18. During six hours steady state, both at 0 °C and at 30 °C the maximum observed deviation from reference is only 0.3 °C @ 30 °C, and in the measurement range of interest to this trial even only 0.1 °C @ 0 °C.

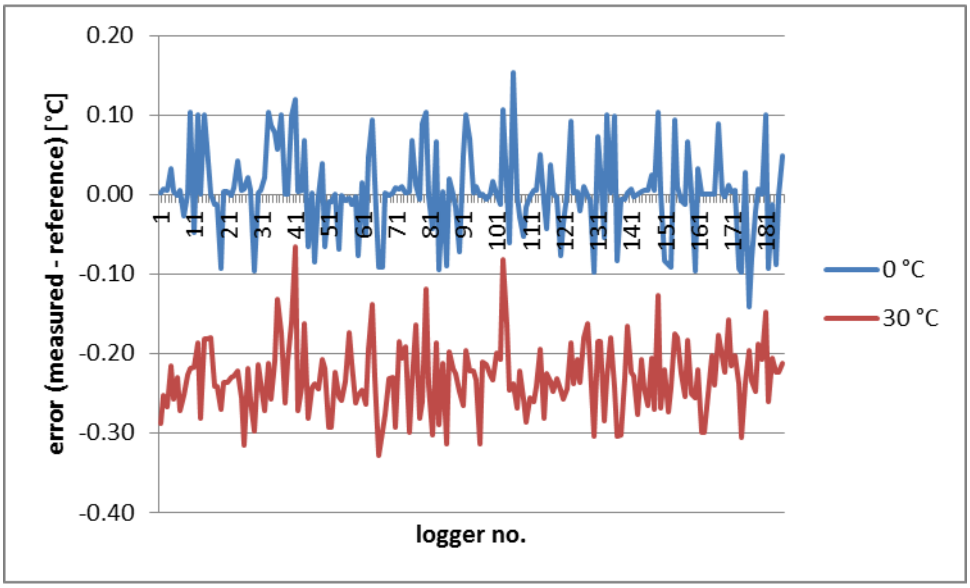


Fig. 18, pre-calibration results (averages over 6 hours period, sampled at 1 min. interval), both at 0 and 30 °C.

For the post-calibration results see Fig. 19 and Fig. 20. When comparing pre- and post-calibration figures note that the logger numbering in Fig. 18 and Fig. 20 may differ. During five hours steady state in the post-calibration the coldest, mean and warmest time-averaged logger recorded resp. 2.0, 2.1 and 2.3 °C. Basically the post-calibration results confirm that the excellent accuracy found during the pre-calibration is still there after completion of the experiment.

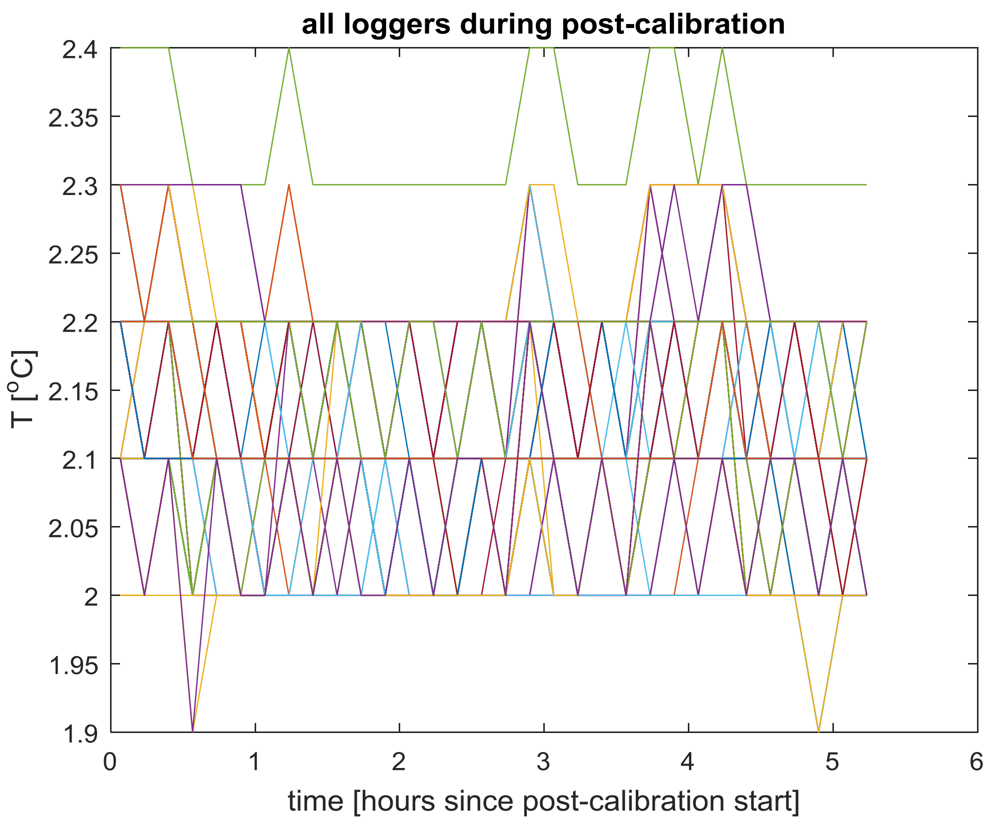


Fig. 19, post-calibration readings at 10 min. interval for all 186 loggers during 5 hours steady state.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

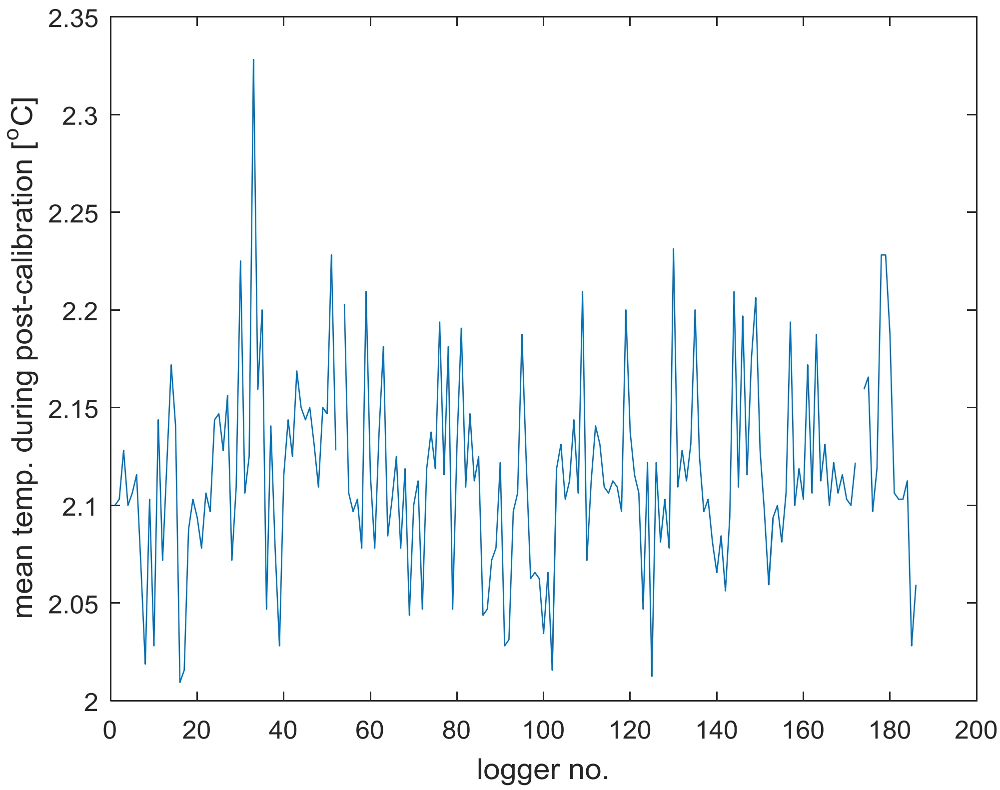


Fig. 20, time-averaged temperatures recorded during 5 hours steady state in a 2 °C chamber for post-calibration.

4.3 Temperatures recorded by experiment's loggers

Two of the 186 loggers went missing, all others recorded flawlessly. Table 5 lists the values for the KPIs defined in section 0. Columns 2 till 7 present the values for the six trial containers.

Table 5, key performance indicators per container (A till C is with floor cover, and D till F without).

KPI	A	B	C	D	E	F
mean temp.	0.1	0.2	0.2	0.4	0.1	0.4
SD temp.	0.6	0.6	0.5	0.8	0.7	0.7
(warmest-coldest), all trip	1.6	2.0	1.6	2.4	2.3	2.9
(warmest-coldest), hot ambient	2.2	2.6	1.9	2.9	3.2	3.6
coldest sensor ID, hot ambient	7	4	7	4	7	4
warmest sensor ID, hot ambient	30	18	27	18	26	28

In Table 5 the mean temperature in container E is distinctly lower than in containers D and F. The cause is unclear, but may be due to an offset of the unit's supply air temperature sensor. The other criteria are less ambiguous.

The three lowest standard deviations (SD temp.) are observed in the three containers with floor cover, showing that the floor cover helps to reduce temperature gradients. The criteria '(warmest-coldest), all trip' and '(warmest-coldest), hot ambient' show the same: the smallest temperature differences are found in the containers with floor cover.

Compare '(warmest-coldest), all trip' for container (A, B, C) to container (D, E, F) to see that the floor cover reduces the average difference between warmest and coldest temperature by approx. 30%. The same holds during the hottest part of the trip (see '(warmest-coldest), hot ambient').

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

The floor cover has no clear effect on the location of the coldest spot: 'coldest sensor ID, hot ambient' is 4 in container B, D and F, and 7 in container A, C, and E. As illustrated in Fig. 11 both are located in the lower half of the two unit-end pallets.
The floor cover has no clear effect on the location of the warmest spot: 'warmest sensor ID, hot ambient' is different in nearly every container, but all locations are in the door-end half of the container, mostly near the doors and against the ceiling. See Fig. 11 for illustration of sensor locations.
Another informative, though more qualitative, way of analysing temperatures is by looking at contour plots. Fig. 21 and Fig. 22 present the contour plots of temperatures for a side view of the containers at respectively the warmest and the coldest moments of the trip. The position of sensors in the 3D container is defined by (length, width, height). Fig. 21 and Fig. 22 plot in the 2D surface spanned by (length, height), using all 31 sensors per container. When at a specific (length, height)-combination multiple sensors are present, the figures present the average of those sensors. For example the temperature at (length, height) = (0, 0) is the average of the readings from sensors 2 and 7, while the temperature at (length, height) = (1.0 m., 0) is the reading of sensor 5 (see Fig. 11).

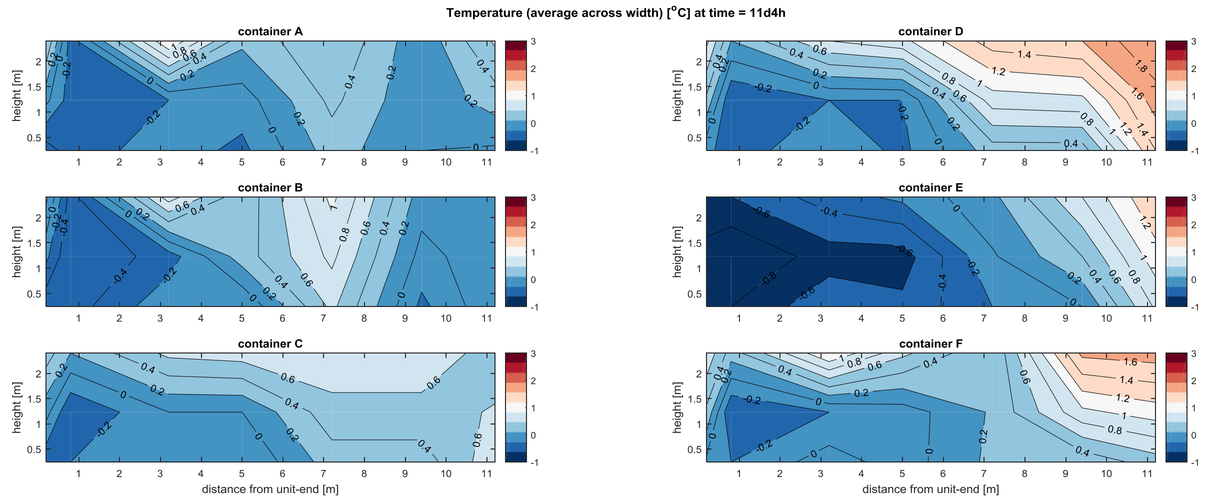


Fig. 21, contour plot of temperatures (side view) when ambient temperature is highest (30 ~ 35 °C).

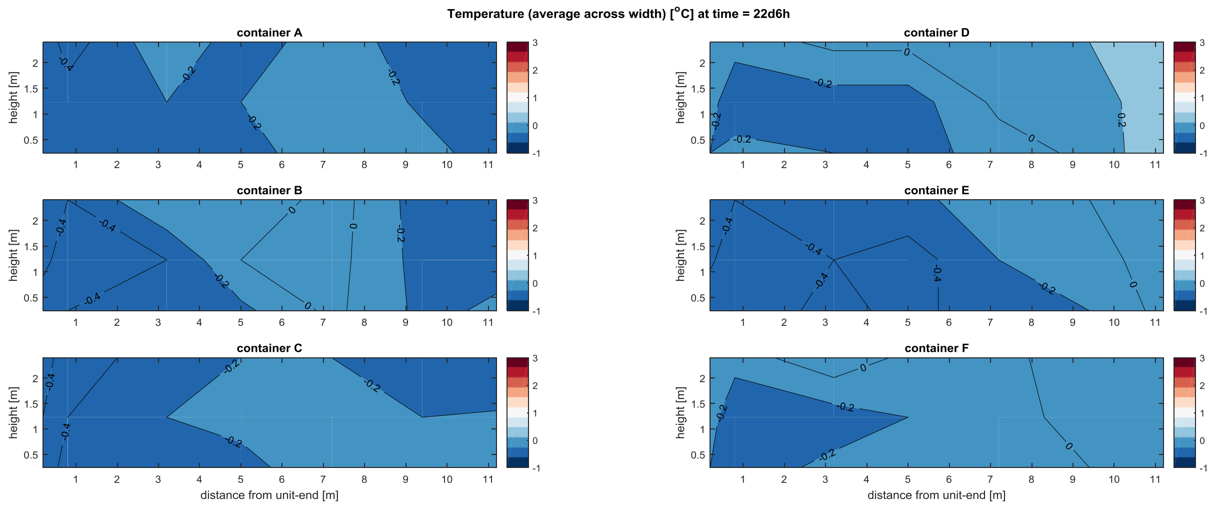


Fig. 22, contour plot of temperatures (side view) when ambient temperature is lowest (2 ~ 6 °C).

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

Fig. 21 nicely visualizes the effectiveness of the floor cover in suppressing high door-end temperatures during hot ambient conditions. Fig. 22 shows that a floor cover has no effect when ambient temperature is ± equal to set temperature.

4.4 Quality

Fig. 23 - Fig. 25 present the three scored quality attributes as a function of average temperature for all Q-trays.

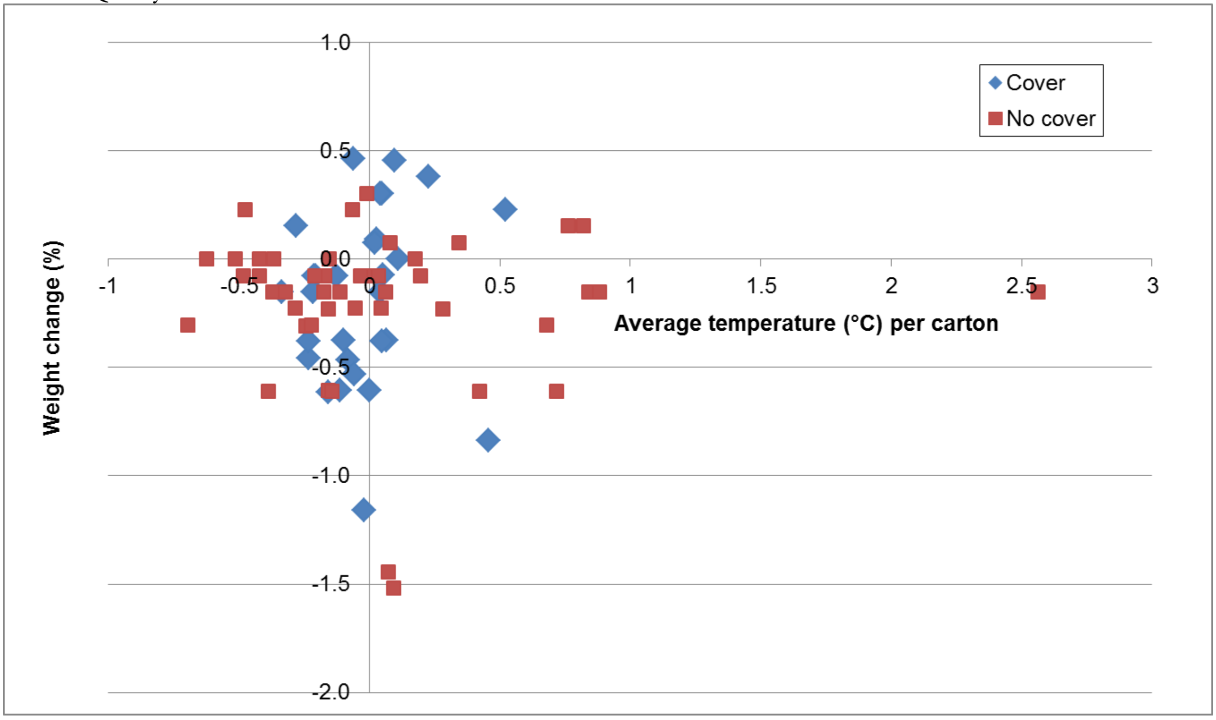


Fig. 23, percent weight change as a function of average temperature.

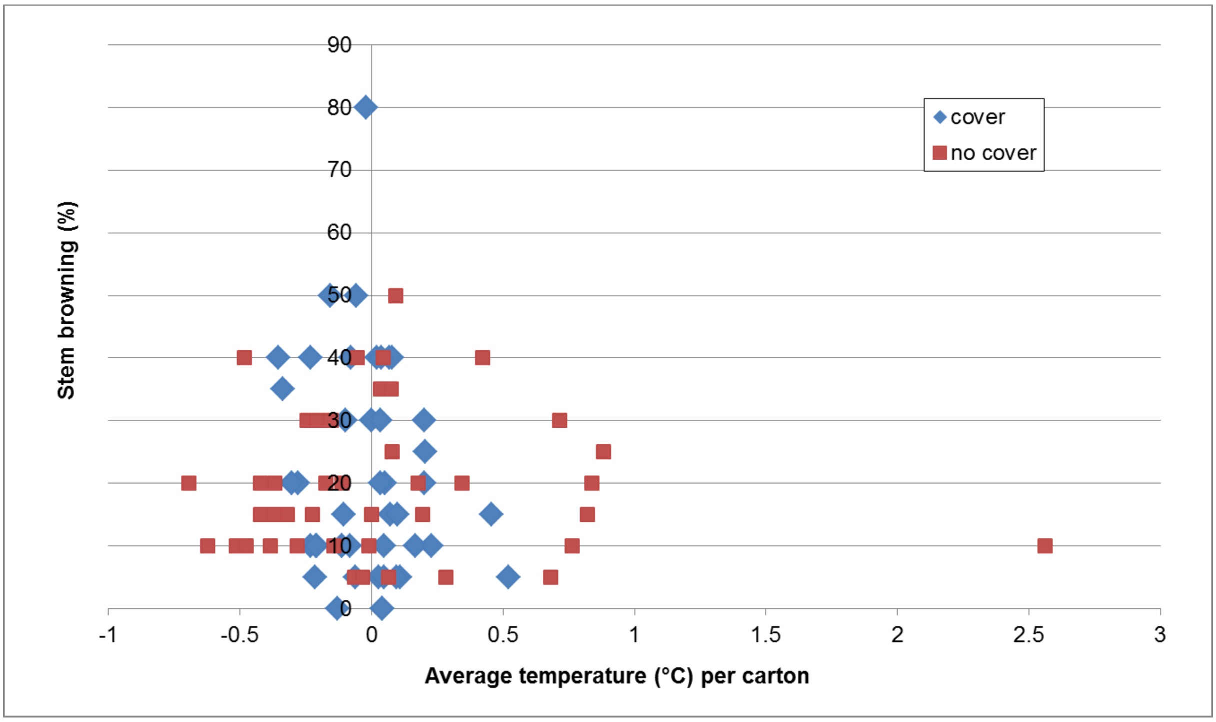


Fig. 24, stem browning as a function of average temperature.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

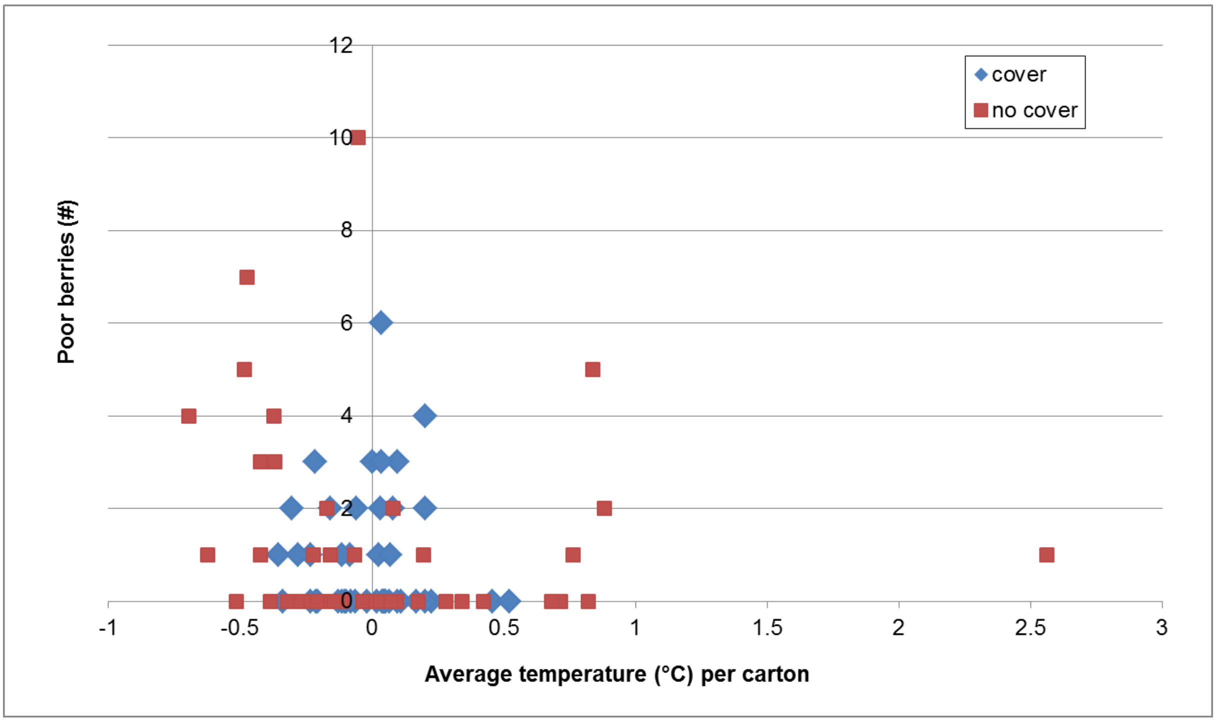


Fig. 25, no. of poor berries per tray as a function of average temperature. Note: this is the count of poor berries found in 5 punnets, arbitrarily selected out of the 11 punnets per tray, where one punnet contains about 100 berries.

Each of Fig. 23 - Fig. 25 shows two comparable clouds of measurement points: blue diamonds for container A-C, and red squares for container D-F. The only visible difference is that the cloud of red squares is a little more stretched out on the horizontal axis: the obvious effect of larger temperature gradients in containers without floor covers. The measurements reveal no correlation between temperature and one of the measured quality attributes. Using a floor cover affects temperature, and temperature affects quality. If the effect of temperature on quality is not observable, then of course the effect of floor cover on quality is not observable either. That is what Fig. 26 - Fig. 28 confirm. Note that Fig. 26 lacks the scores for container C, which is because it was just forgotten to weigh the trays during unstuffing.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

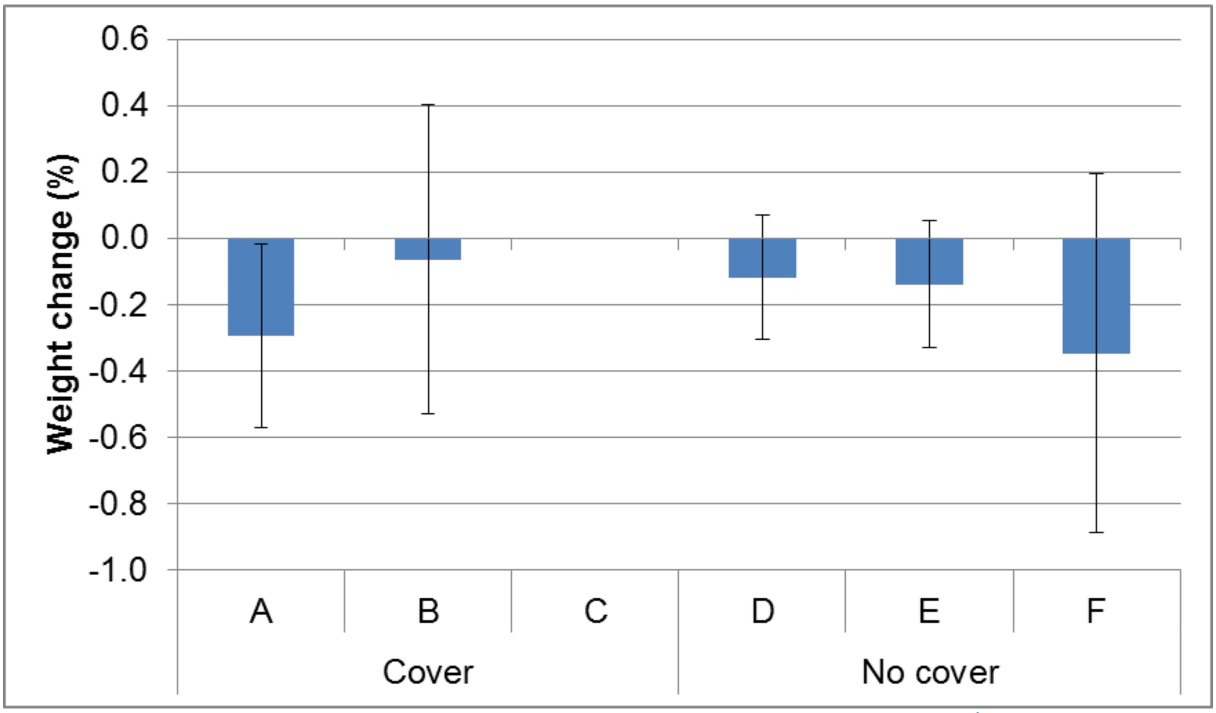


Fig. 26, average percent weight change as a function of container with error bars indicating the ± 1 STD-range.

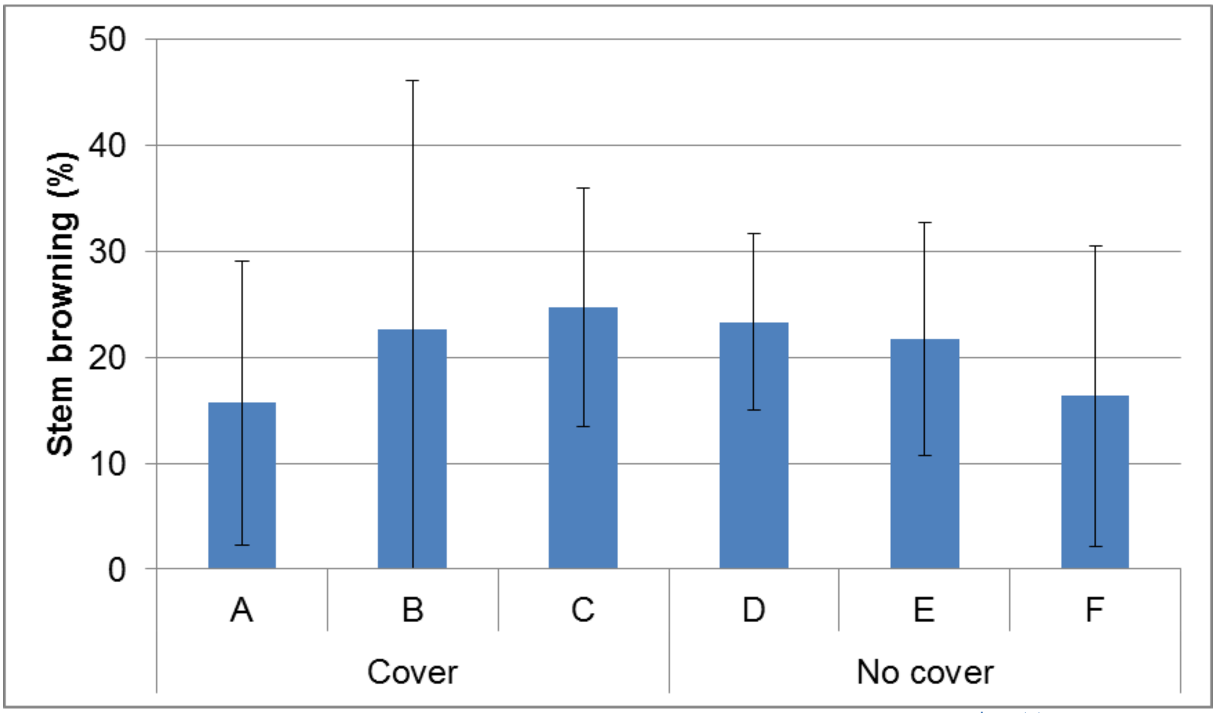


Fig. 27, average percent stem browning as a function of container with error bars indicating the ± 1 STD-range.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

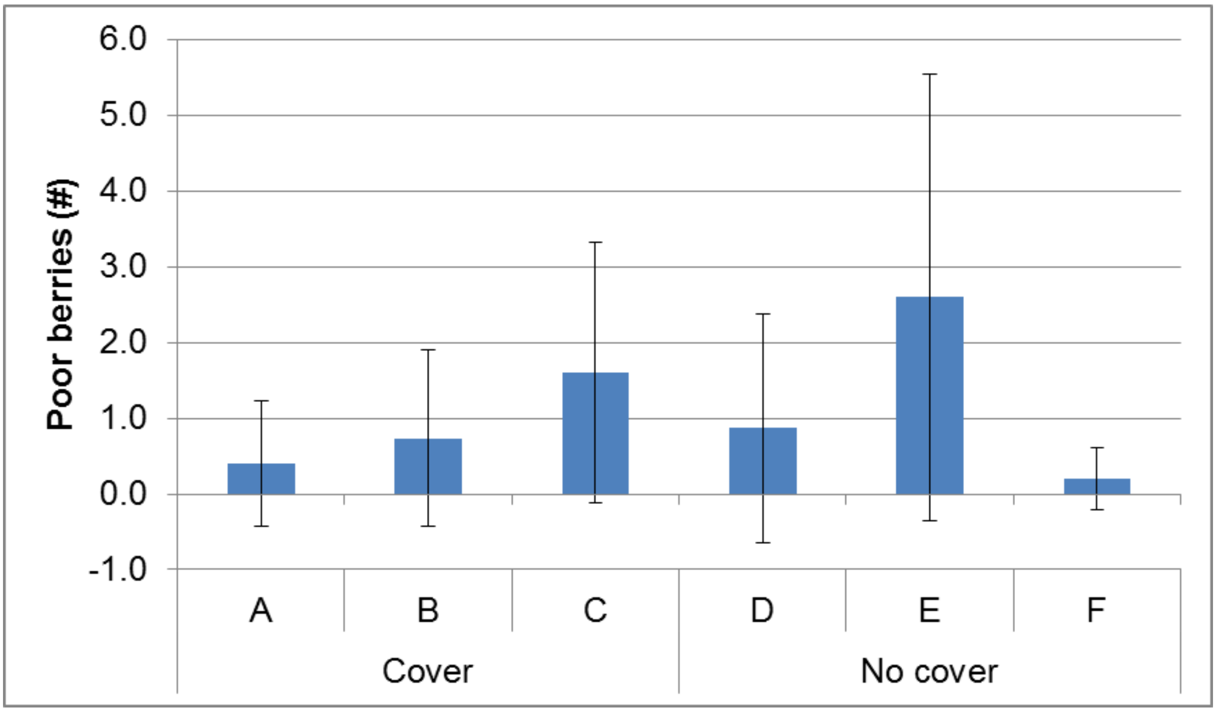


Fig. 28, average number of poor berries as a function of container with error bars indicating the ± 1 STD-range.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

5 Discussion

5.1 Temperature

A priori a concern was whether the floor cover would limit the air flow in the lower parts of pallets 1 till approx. 7 too much, resulting in hot spots due to autonomous heat production in that zone. None of that was observed. Apparently, in this low respiring fruit, the floor cover allows for sufficient airflow in the lower regions of the pallets at the unit-end.
The trial containers were carried on deck. Many reefer containers are carried in holds below deck. In the holds ambient temperatures are usually higher than on deck. Hence it is to be expected that in many shipments floor covers will have a bigger effect than observed in this trial. A shipper cannot influence the position of his container on board the vessel.
How will the floor cover perform in transport of different products? This trial proves the positive temperature effect of this floor cover for a load of properly precooled grapes. Of course the results apply to a wider range of commodities. The same effect is to be expected in any load of properly precooled low-respiring product. It remains to be seen how this floor cover performs in commodities which are not properly precooled or have a high autonomous heat production. In this respect a test on a load of palletized bananas would be informative.

The internal container width is 2.29 m, while the width of two pallets next to each other is 1.00 + 1.20 = 2.20 m. What to do with the remaining 9 cm? From a temperature management point of view it is best to minimize direct contact between the 'warm' container walls and the fruit, i.e. to stuff the container such that at each side there is a 4.5 cm gap between the side walls and the load. This is what was done in the lab conditions experiment reported in Lukasse & Staal (2016a & b). During stuffing of the trial containers the fork lift drivers placed all pallets against the container side walls, leaving a gap in the middle of the container, over the complete length and height (see Fig. 11). It was a well-considered choice to not interfere and let this trial run under practical conditions. The procedure of the fork lift drivers is convenient both during stuffing and during unstuffing, but suboptimal from a temperature management point of view. Fig. 29 illustrates the consequence. Fig. 29 differs from Fig. 22 in only one way: Fig. 29 provides a top view, while Fig. 22 provides a side view. Fig. 29 visualizes that temperatures near the walls are warmer than near the gap between the two pallet rows, esp. in the containers without floor cover (D till F).

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

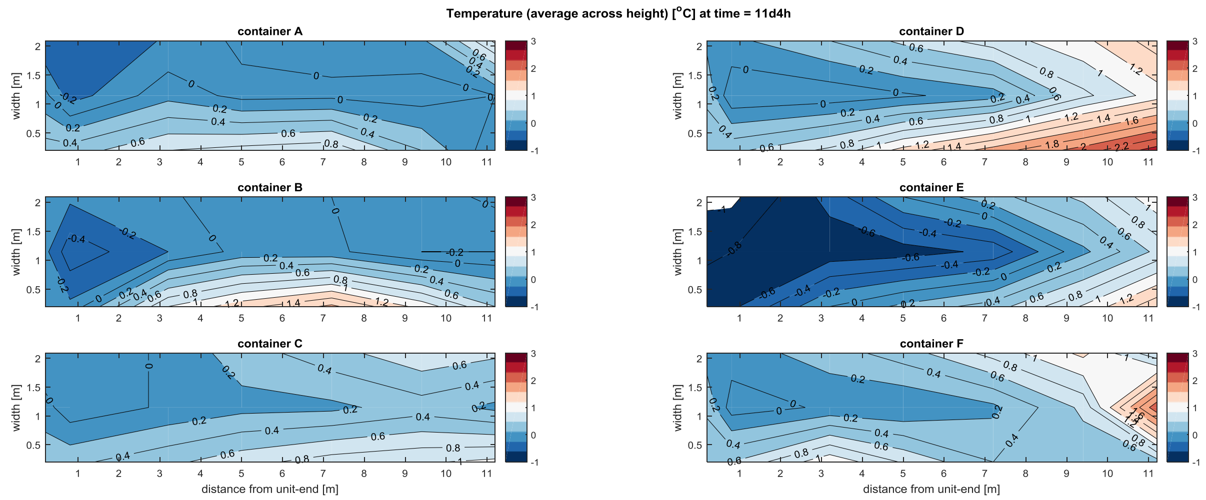


Fig. 29, contour plot of temperatures (top view) when ambient temperature is highest (30 ~ 35 °C).

During stuffing it turned out that the floor cover could not stand the weight of the forklift. The cover tore in many places. In the experiment the tears were repaired with duct tape. For future application the robustness of the floor cover deserves further attention. How harmful is it if it tears to some extend during stuffing? Could another, more resilient, material be used? Another option is to cover the floor in parts: e.g. cover the relevant floor area under pallet 1 and 2, place pallet 1 and 2, cover the relevant floor area under pallet 3 and 4, place pallet 3 and 4, etc.

5.2 Quality

In a lab experiment Mensink & Westra (2017) stored grapes cv. Thompson Seedless from Greece at three different temperatures: -1.5, -0.5 and 3.5 °C. After two weeks of storage the quality of the batches stored at -1.5 and -0.5 °C was significantly better than that of the batch stored at +3.5 °C. They also noted that the biological variation of the starting material was high. The biological variation resulted in a relatively large value for the least significant difference between treatments, *i.e.* made it difficult to see the effect of different treatments.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

In this trial the coldest trip-averaged temperature recorded in a Q-tray was -0.7 °C, and the warmest +2.6 °C. In view of Mensink & Westra (2017) one would expect to observe an effect of an average temperature difference of 3 °C during a 24 days trip. So, why is there no correlation between observed temperature and quality? Below paragraphs seek an answer to that question.
A weight change of one, or maybe even a few, percent was anticipated, but it turned out to be less than ± 0.5% for most Q-trays. The measurement procedure, and possibly also the equipment, has been inadequate for assessing these very small weight changes, let alone for *differences* between these small weight changes. During stuffing and unstuffing two different scales, commercially used at the facilities of stuffing/unstuffing, were used. Both had a resolution of 1 gram (x.xxx kg). However during stuffing the weight was written down in a resolution of 10 gram (x.xx kg). The accuracy of the scales undoubtedly suffices for its ordinary purpose, but is unknown to the authors. The trays weigh approx. 6.6 kg. Hence, 0.5% weight change is 33 g. To accurately assess a full 0.5% weight loss requires resolution and accuracy of measurement equipment in the order of a few g. In terms of resolution that requirement was not met, in terms of accuracy it is unknown if that requirement was met. To assess subtle differences in weight change even higher requirements apply to resolution and accuracy. If the resolution and accuracy requirements are met, then it is still questionable whether the way of working is suited to assess weight loss of grapes. Probably the change of water content of the trays has the potential to be the dominant factor in the observed weight change. The moisture content of cardboard may easily reach 10 (g/100 g dry solids) (e.g. Parker et al., 2006). This leaves the impression that changes in water content of the trays have the potential to eclipse the fruit's minor weight change.
The quality attribute of stem browning is a subjective score. The quality inspector views the punnets, estimates which visible share of the stems does not look fresh green and then assigns his score. Measurement errors of 10 – 20% seem inherent to the way of scoring. Differences in the browning may be influenced by pre-shipment factors, like farm, place in the vineyard, place on the vine, time between harvest and stuffing. All those factors are unmeasured and unknown in this experiment. What is known is that the fruit originated from multiple farms.
Finally for the quality attribute of poor berries basically the same applies. The quality inspector may easily make measurement mistakes (what exactly is poor?). The true difference may be influenced by other factors than temperature. Moreover the scores are very low: mostly 0 till 6 poor berries, out of the approx. 500 berries present in the evaluated punnets. Though a few poor berries make a punnet unsuitable for sales, it is hard to assess quality *differences* in this way.

5.3 On the effectivity of the floor cover

Though the floor cover has a positive effect on temperature homogeneity, no effect on grape quality was observed. How to appreciate that? Quality loss of grapes is influenced by temperature, hence the floor cover must have a positive effect on grape quality. Apparently in this trial the effect is too small to observe it between other unknown effects, and measurement inaccuracy. Hence the use of the floor cover was pointless for the grapes used in this trial. On the other hand the floor cover has a positive effect on temperature, and therefore mitigates the risk of temperature-related quality issues in grapes. It may therefore well have an added value in other shipments of other grapes or other fruit.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

6 Conclusions

This trial's floor cover reduces the temperature difference between warmest and coldest measurement location in shipments of precooled grapes by approx. 30%. The effect on fruit quality could not be assessed in this trial.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

7 Recommendations

Where to use the floor cover is a commercial decision: it's a trade-off between extra costs, extra work and extra waste against a reduced risk of temperature-related quality issues. A shipment reaching the receiver with temperature-related quality issues concentrated at the door-end would have benefited from the floor cover. The results show that it is needless to use the floor cover in every grape transport. If it is decided to gain more experience with using the floor cover, then it is recommended to start the use of the floor cover in transports of weak batches of temperature sensitive grape cultivars, travelling in trade lanes with long transit times and hot ambient conditions.

It is recommended to improve the floor cover's resilience to forklifts driving over it, or to install it in parts such that the forklifts don't need to drive on it during stuffing.

It might be interesting to learn more about the effect of the floor cover on the rate of temperature pulldown. It is therefore given into consideration to repeat the experiment on a hot-stuffed cargo. Hot-stuffing is standard practice in the (large volume) banana trade. Most informative will be a long shipment through hot climates, e.g. Ecuador to Europe with containers placed below deck.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

Appendix 1, test log

Date [dd-mm-yyyy]	Description of activities
14-12-2016	pre-calibration of temperature loggers
20-01-2017	preparation and labelling of experimental pallets
21-01-2017	stuffing of all six trial containers
13-02-2017	reefer unit downloads taken at terminal in port of destination
14-02-2017	unstuffing of trial containers + quality inspection
15-02-2017	post-calibration of temperature loggers

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

References

Anonymous (no year). Hamburg Süd reefer guide.

Cronje P., Aunstrup S., Bosman J., Norrefeldt V., Sibiya G. (2015). Ambient loading of citrus fruit to cold sterilization markets – 2015 experiments.

Defraeye T., Nicolai B., Kirkman W., Moore S., Niekerk S. Van, Verboven P., Cronje P. (2016). Integral performance evaluation of the fresh-produce cold chain: A case study for ambient loading of citrus in refrigerated containers. Postharvest Biology and Technology. 112, pp. 1-13. Doi 10.1016.

Dodd M.C., Worthington-Smith P. (2006). Managing airflow in reefer containers benefits fruit quality. IIR-IRHACE, Auckland.

Elíasson S., Margeirsson B., Arason S. (2013). Improved reefer container for fresh fish. Matís - Icelandic Food and Biotech R&D report no. 01-13. ISSN1670-7192.

Getahun S., Ambaw A., Delele M., Meyer C.J., Opara U.L. (2017). Analysis of airflow and heat transfer inside fruit packed refrigerated shipping container: part II – evaluation of apple packaging design and vertical flow resistance. *Journal of Food Engineering*. pp. 1-12, DOI 10.1016/j.jfoodeng.2017.02.011.

Haan H. De (no year). De Beer's consolidated manual on the transportation of perishable cargo in reefer containers.

Lawton A.R. (1995). Controlling the temperature of cargo in a container. UK patent GB 2282873.

Lawton A.R. (1999). The splitter board system for improving temperature distribution in ISO containers. Vol. IV (paper 446) in proc. of ICR1999, Sydney, Australia.

Lukasse L.J.S., Staal M.G. (2016a). Optimizing air flow distribution in maritime refrigerated containers. Wageningen UR Food & Biobased Research report no. 1621.

Lukasse L.J.S., Staal M.G. (2016b). Optimizing air flow distribution in maritime refrigerated containers. accepted for publication in Acta Horticulturae.

Mensink M., Westra E. (2017). Effect of storage temperature and time on quality of Thompson seedless table grapes from Greece. Wageningen Food & Biobased Research report no. 1736.

Montsma M., Staal M., Lukasse L. (2011). Optimizing shipment of lily bulbs in 40ft reefer containers. Wageningen UR Food & Biobased Research report no. 1246.

Norrefeldt V. (2015b). Validation of Maersk Line Reefer Simulation Model – orange and mandarin in supervent, IFCO and open top. Fraunhofer IBP report EER-004/2015/956.

Parker M.E., Bronlund J.E., Mawson A.J. (2006). Moisture sorption isotherms for paper and paperboard in food chain conditions. *Packaging technology and science*. **19**, pp. 193-209. DOI 10.1002/pts.719.

© Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research

Acknowledgements

This work is part of the GreenCHAINge project workpackage 1.
Scientific field experiments like this are only possible if all parties involved, give their full cooperation. That happened. We are therefore very grateful for the excellent support received from the trial partners Maersk Line (represented by Steen Aunstrup and Johann Bosman), Bakker Barendrecht (represented by René Geelhoed), Horizon Fruits (represented by Cobus van der Merwe) and Otflow (represented by Otto de Groot).
We acknowledge foundation TKI Horticulture for providing part of the project funding.

 © Wageningen Food & Biobased Research, institute within the legal entity Stichting Wageningen Research