Citrus breathes easier in smarter packaging

Ambient loading relieves logistics pressures, but presents cold sterilisation challenges that can only be resolved with packaging that allows optimal airflow.

THE VOLUME OF CITRUS FRUIT exported from South Africa under phytosanitary requirements has increased over recent years, resulting in pressure on the limited pre-cooling facilities at local ports. The fact that more citrus is being exported than the pre-cooling capacity available, leaves the industry with a logistical headache.

In response to this challenge, ambient loading has become an essential component of the South African citrus industry's cold chain, as it reduces strain on the limited cold store facilities.

The challenge

Ambient loading simply means that palletised fruit is loaded into refrigerated containers at ambient temperature. The containers are equipped to remove the field heat and cool the fruit over a period of two to three days.

However, current citrus packaging materials are highly resistant to airflow, it can take up to five days before sufficient cold air reaches all the fruit and the set point temperature of < 2ºC is achieved. These variations in cooling performance (rate and uniformity) mean that ambient loads do not always meet the requirements of the sterilisation protocol set by full cold sterilisation markets. These loads can, therefore, only be

Clearly the ventholes of the boxes on this pallet do not allow optimum ventilation.

exported under shipment durations long enough to allow for adequate exposure days between the port and the destination market.

The main factors influencing cooling performance of fruit loaded at ambient temperature are the initial pulp temperature and variation in the airflow rates through the pallets. Airflow rates are, in turn, greatly influenced by carton designs and the extent to which they can make the most of a container's air delivery system. The varied airflow distribution observed in refrigerated containers contributes to an increased incidence of chilling injury (in high flow areas) and pallet hot spots (in low flow areas).

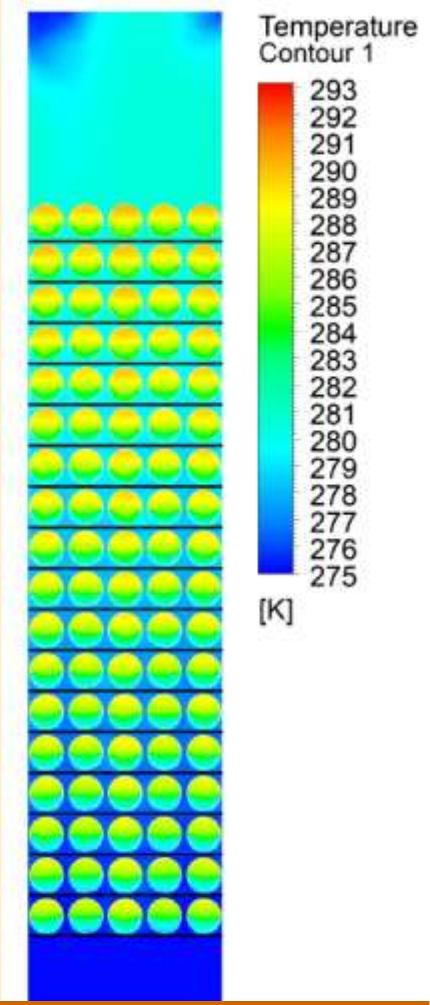


Figure 1: Temperature gradient of ambient loaded (warm) citrus fruit during refrigerated container shipping. This CFD model was used to predict to what extent cooling is delayed when packing citrus fruit with unventilated trays in open-top cartons.

By improving the ventilation capabilities of packaging systems, the use of ambient loading can be extended to further reduce the pressure on South Africa's limited pre-cooling facilities. Handling times will also be shortened, resulting in faster shipping and the associated benefit of fruit reaching destination markets quicker.

Finding the answers

In an effort to address these issues, Citrus Research International (CRI) initiated research to quantify the performance of current citrus packaging designs, and to identify potential solutions or strategies. The study had four specific objectives:

1. Perform a survey of local packhouses to understand the design problem better.
2. Design novel carton vent and pallet base configurations based on total unobstructed area.
3. Commercially evaluate current packaging systems during forced-air cooling and refrigerated container shipping.
4. Compare the cooling performance of current designs and identify potential solutions for optimisation.

Co-funded by the Postharvest Innovation Programme, the study was led by Dr Tarl Berry a researcher for the CRI and Department of Horticultural Science at Stellenbosch University. He was assisted by Professor Paul Cronjé and Jade North-Dewing (an MSc student), both from CRI and Stellebosch University, and Sung-hee Chung, a post-graduate student at the Stellenbosch University.

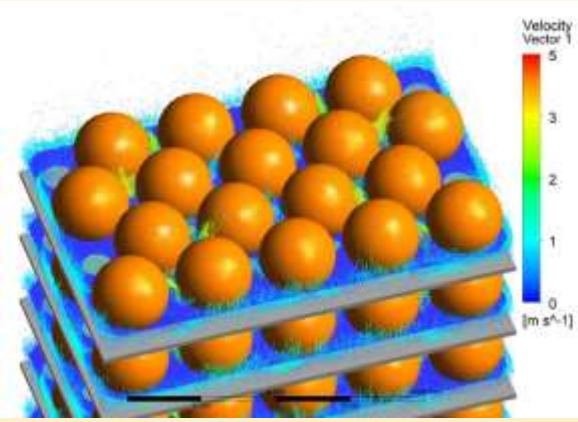


Figure 2: Predicted pathways of airflow between fruit when packed with ventilated trays in open-top cartons.

Project methodology and findings

The packaging systems survey was performed in 2019 and 2020, using cartons collected from multiple cold stores in Durban, Port Elizabeth and Cape Town. The evaluation included carton dimensions (footprint and height), vent hole design (size, positions, number) and the palletisation method. The latter included an investigation into the effect of additional packaging material (e.g., securing sheets and trays), as well as how pallet bases restrict airflow. All the packaging systems were evaluated by emulating pre-cooling as well as container cooling.

The survey results showed that 85% of SA citrus exporters use A15C, E15D and E10D cartons. The open-top cartons (E15D and E10D) cooled substantially slower than the A15C cartons.

Researchers further found that cross-stacking caused severe restrictions; in fact, where carton layers meet, the resistance to airflow increased more than threefold.

Findings also showed that the packaging system must be considered holistically. For example, optimising the pallet base to improve ventilation is only beneficial when the rest of the pallet is optimised, and non-obstructive securing sheets reduced airflow resistance by 45% and 18% for the E10D and E15D cartons, respectively.

As far as vent hole design is concerned, open-top cartons must have much larger vent hole areas than A15C cartons to achieve similar cooling performances. Future carton designs should furthermore adopt the 100mm-grid approach, which drastically improves vent hole alignment during stacking. This approach can, in part, address vent hole obstruction during cross-stacking. The 100mm approach also makes it easier to design pallet bases with more optimal slat positions, which could improve ventilation by ~10%.

The use of trays in cartons greatly increases the probability of higher temperatures during shipping. Unvented trays increase pressure loss by 110%; ventilated trays increase pressure loss by 56%. Trays should be avoided at all costs in phytosanitary sensitive markets. However, if trays must be used, they need to be ventilated.

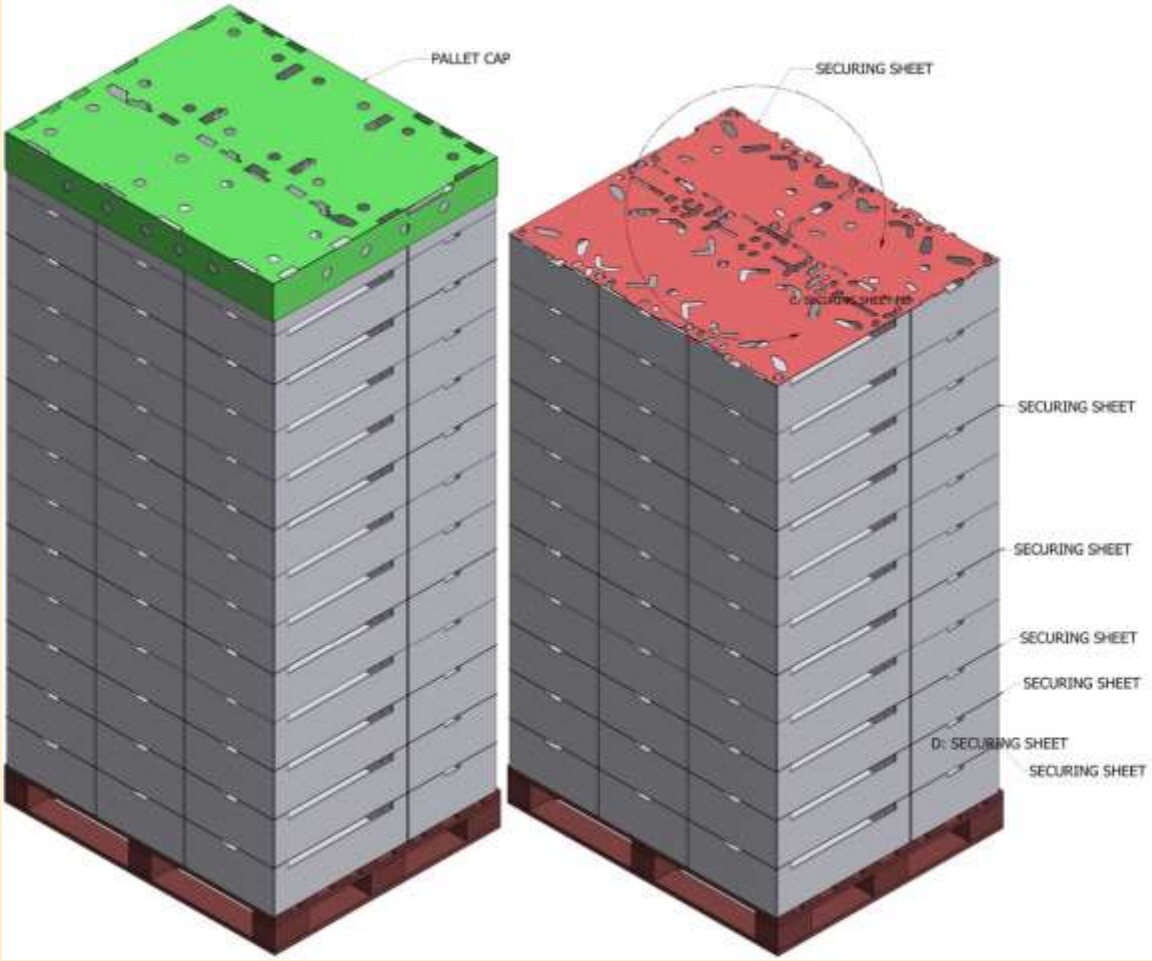


Figure 3: Illustration of the computer-aided-design (CAD) drawings, in this case, the E15D and its respective pallet base, securing sheets and pallet cap. CAD drawings were completed for multiple packaging combinations, which could then be used to accurately calculate multiple parameters, such as the ventilation area at each of the interfaces.

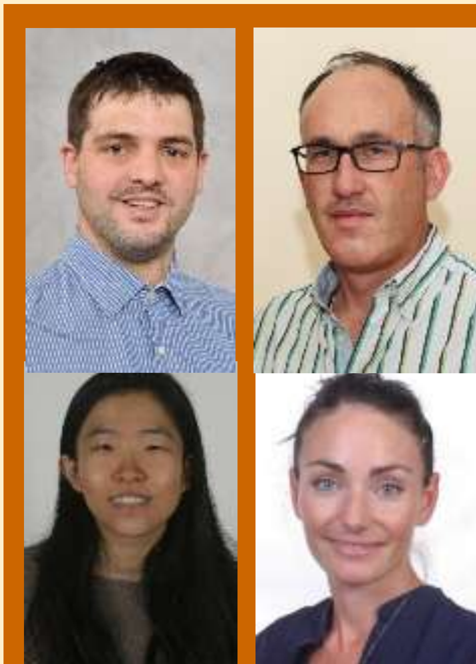
The way forward

The research study showed that improving ventilation is not a simple matter. For instance, given the extent to which cross-stacking restricts airflow, column stacking should be the preferred method to improve cooling performance. However, column stacking compromises the pallet's overall stability. Stability issues must therefore be addressed first.

A finding that the industry has already actioned, is that using correctly designed securing sheets would be one of the most practical ways to reduce airflow resistance in open-top citrus packaging. Furthermore, EU markets are now required to use ventilated trays and securing sheets that are designed with non-obstructive vent holes.

Despite its many useful and significant findings, the study showed that a singular recommendation regarding vent holes is not possible. While cooling is primarily determined by the ventilation holes in a carton, a great number of other variables interact with vent hole design. To resolve the design problem, a more dynamic approach is needed.

A significant finding of this study, was that the pallet structure primarily operates as an electrical circuit (Kirchhoff's first law of circuitry), with the fan, carton interiors and vent holes functioning as 'batteries', 'wires' and 'resistors', respectively. Flow rate is thus current, pressure is voltage and constriction/obstruction is resistance. A similar approach is applied by the mining industry, where complex ventilation systems are likewise calculated.



Clockwise from the top: Project leader and researcher for the CRI and Department of Horticultural Science at Stellenbosch University, Dr Tarl Berry, was assisted by Prof. Paul Cronjé and Jade North-Dewing (MSc student), both from the CRI and Stellenbosch University, and Sung-hee Chung, an MEng student at the Stellenbosch University.

THE PROJECT'S ECONOMIC IMPACT

Chilling injury related damage equate to millions of rands of losses per year. The findings of this study are already being introduced, at multiple levels, into industries packaging, resulting in more effective phytosanitary applications and the need for less destructive cold treatment applications.

This modelling approach can be used to describe the whole pallet structure as a 3D flow circuit and, with the correct parameters, characterization of the system is possible almost instantaneously. The model could furthermore be used to generate performance indices for every possible packaging scenario, resulting in a practical guide the industry can use for ventilation design. This concept is currently the focus of a Meng research project and is showing promising outputs.

PROJECT INFORMATION

Project title: Integration of pallet bases and carton designs to improve ventilation of containerised citrus exports

Principal investigator: Dr Tarl Berry

Duration: 01/03/2019 - 30/07/2021

PHI Programme and Industry Contributions: R284 385 and R284 385

Lead institutions: University of Stellenbosch

Beneficiary: The South African citrus industry

Human resource development: 2 PhD, 1 MSc student and 1 MEng student

Focus area: Carton design, cooling, pallet design, postharvest quality

In 2019, South Africa exported over 127.5 million cartons of 15 kg each to global markets, making it the second-largest exporter of citrus fruit in the world.