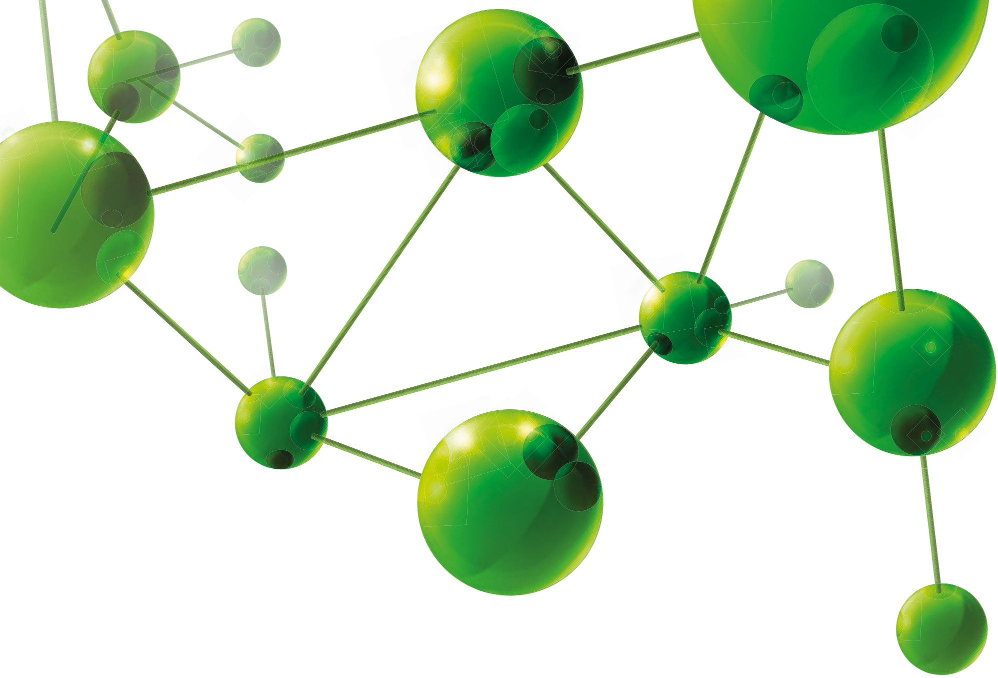
Excellence through Innovation

phi post-harvest innovation PROGRAMME



Celebrating excellence

Showcasing innovation

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introduction

The Post-Harvest Innovation (PHI) Programme is a longstanding public-private partnership between the Department of Science, Technology and Innovation (DSTI) and Industry, with the Fresh Produce Exporters' Forum (FPEF) serving as the implementing agent. Since its inception in 2007, the Programme has provided a critical platform to facilitate post-harvest research, development and innovation – in support of the South African fresh horticultural export industry.

To commemorate the fifth phase (PHI-5) of the Programme, a series of articles was commissioned and compiled in this publication to showcase the research and development (R&D) projects undertaken between April 2022 and March 2026, reporting on the majority of R&D projects conducted under PHI-5.

Collectively, the R&D projects addressed important challenges affecting the export cold chain, including post-harvest diseases, pests, physiological disorders, packaging failure, sanitation, fumigation and handling practices that can reduce product quality, shorten shelf life, increase export losses and threaten market access. Several projects specifically focused on the mitigation and control of post-harvest pathogens and pests, as well as the development of alternative phytosanitary and sanitation treatments to meet increasingly stringent international market and regulatory requirements. One project also focused on training and skills development within the Cape Flora industry.

Over the duration of PHI-5, the Programme has continued to support research aimed at addressing critical technology gaps and export challenges across the horticultural value chain, whilst also providing financial support to participating students and interns and contributing to postgraduate training, skills development and transformation.

PHI-5 was implemented in partnership with Hortgro, the South African Table Grape Industry (SATI), the South African Subtropical Growers' Association (Subtrop), which also manages the affairs of the South African Avocado Growers' Association (SAAGA), Cape Flora SA (CFSA) and Berries ZA. Thirteen R&D projects were undertaken by researchers from Stellenbosch University, the University of KwaZulu-Natal, AgriSMART SA, ExperiCo – Agri-Research Solutions and TerraClim. R&D project costs were jointly funded on an equal basis by the DSTI, through its Sector Innovation Fund (SIF), and the participating industry associations.

The FPEF acknowledges the DSTI, the PHI Steering Committee, participating industry partners, researchers, students and interns for their role in the implementation of PHI-5.

Optimising post-harvest packaging of table grapes

Packaging solutions to help combat decay during post-harvest storage

Choosing the most optimised packaging combinations is vital for growers aiming to export premium-quality table grapes.

The presence of plant pathogens such as *Botrytis cinerea*, *Penicillium expansum*, *Alternaria alternata*, *Cladosporium spp.*, and *Aspergillus spp.* can impact the quality of table grapes destined for export.

A jointly-funded research project by the South African Table Grape Industry (SATI) and the Post-Harvest Innovation (PHI) Programme was spearheaded by Dr Johan Fourie, Dr Alana den Breeyen and Daniël Viljoen of ExperiCo. They sought to ascertain how to optimise post-harvest packaging to prolong storage and maintain table grape quality.

Dr Alana den Breeyen of ExperiCo.

Sulphur dioxide use in packaging is well established for limiting decay during shipment and storage. However, its efficacy is influenced by several factors, including pre-harvest quality, infection levels and post-harvest conditions. These factors were investigated in this study, initiated in 2022, which involved a series of controlled trials evaluating their combined effects on decay control and post-harvest performance.

A storied history

Sulphur dioxide (SO_2), long recognised for its role in combating decay in the table grape industry, has been in use for just over a century, with its earliest documentation traced to the United States. Dr Fourie referenced the work of Lazar Ginsburg, a leading South African researcher at the Fruit and Food Technology Research Institute during the 1970s and 1980s, noting the close collaboration between South African scientists and the prominent US researcher, Dr K.E. Nelson. "What is particularly interesting," he said, "is that whilst US researchers were slightly ahead in developing the second-stage SO_2 sheet, the work was closely linked with South African research."

Yet Dr Fourie stressed that innovation remains as critical today as it was then. Shifting market expectations and increasingly complex logistics and supply-chain ecosystems now demand far more than good commodity quality alone. As packaging has evolved into a strategic contributor across both the supply and value chains, Dr Fourie and his team embarked on a programme to identify and define current best p ractices suited to these new realities.

The changing landscape of SO_2 sheets

Manufacturers had introduced new types of SO_2 sheets. One of the main objectives of the research was to test the SO_2 release patterns and efficacy of different SO_2 sheet types for confining decay.

For Dr Fourie, SO_2 remains a key and well-validated intervention for managing post-harvest decay caused by *Botrytis cinerea* in table grapes.

Role of SO_2 and packaging combinations

Dr Den Breeyen explained that a decision had to be made about every component of packaging –

from the SO_2 sheet, liner bag, moisture absorbent material and punnet type to ventilation, perforation, packer's knowledge and cooling.

Considering this, SO_2 is a vital antimicrobial and antifungal agent, particularly in the post-harvest storage of table grapes. However, research has shown that thin-skinned table-grape cultivars may develop SO_2 burn when overexposed. This project evaluated SO_2 sheets against the *Botrytis cinerea, Alternaria alternata,* and *Penicillium spp*. Four table-grape cultivars, namely 'Sweet Celebration™', 'Sweet Globe™', 'AUTUMNCRISP®, and 'Crimson Seedless', were included.

AUTUMNCRISP® & Crimson Seedless in heat-sealed punnets.

Specific amounts of SO_2 must be released, in the right combination, prior to and during cold storage, says Dr Fourie. "If the SO_2 in the sheet is too low, the incidence of decay increases; if too high, the table-grape berries incur SO_2 damage."

The mechanics of a SO_2 sheet

SO_2 sheets used for preserving table grapes during storage have a dual-release mechanism. The sheets absorb moisture from the table grapes and environment, creating a chemical reaction. The first release is a quick burst that aims to kill pathogens whilst stabilising the table grape itself. The second is a more moderate, modulated release with the goal of constraining the growth of already present infections and controlling the spread between berries.

Regarding the chemistry involved, specifically sodium metabisulphite ($Na_2S_2O_5$), Dr Fourie observed that high humidity was enough to kick-start the process. Though SO_2 sheets need moisture to activate, it is not "free water". The latter had to be avoided, as it could have a damaging effect on berries, releasing SO_2 too quickly. Berry cracking, decay development and initiation of infections could follow. He confirmed that the right term for this type of moisture was relative humidity (RH), which is the water vapour in the air. "The higher the relative humidity in the environment, the quicker SO_2 will be released from the first stage. If very low, the slower and lower SO_2 will be released."

He further explained that the SO_2 sheet can be made of either paper or plastic. The sheet comprises a wax- or resin-based matrix incorporating $Na_2S_2O_5$ particles as the active component. In addition, one of the matrix surfaces is uni-directional, i.e. coated with the active ingredient, which is also the origin of that first, quick release of SO_2. Everything revolves around the matrix in which the $Na_2S_2O_5$ is embedded. Ultimately, that determines the duration and preservation level.

Getting it right

Dr Fourie reiterated the importance of knowing what the sheet does, and over what duration SO_2 is released. He explained that the components incorporated into the matrix constitute proprietary information. In the past, manufacturers would typically specify the mass of the active ingredient (e.g. 6 or 7 g). However, the performance is more dependent on the matrix formulation as a whole, rather than solely on the grammage. "In the old days when it was paper only, and not today's plastic, the grammage of SO_2 was quite important – then we distinguished between 6, 7, or 9 g, to know how long SO_2 would last and the preservation level."

He said it is vital that growers learn more about SO_2 sheets and know for how long they plan to store the table grapes so that when they are packed, growers can make provision for long-term storage – for example, by using a slightly less perforated bag, and SO_2 sheet of a higher release rate in the second stage. However, storage and packaging are often not clear from the outset; plans could change depending on a number of variables or decisions made by stakeholders.

Liner bags

When considering liner bags as part of packaging, another important objective of the research was to determine the role of different inner packaging combinations in post-storage quality. Dr Fourie took great care to explain the role of the liner perforations, specifically the perforation area. He defined it as being determined by the number and size of the holes and the dimensions of the bag. For example, in reference to a liner described as 120 by 5, it simply means 120 holes of 5 millimetres each – which relates to the calculated perforated area of a liner.

He said that if the perforated area is too large, "SO_2 can be lost to an extent where it is no longer present at an effective dose, and hence decay control is impaired." The bigger the holes, the lower the RH, the lower the SO_2 flowing out of the larger perforations of the bag. Conversely, if the "perforated area is too low, free water may accumulate, which relates to berry cracking and SO_2 damage".

The confinement of moisture or retention depends on the perforation area of the liner bag. A sufficient concentration of SO_2 is necessary to maintain microbial control over time. Bags with fewer perforations retain more moisture, leading to higher SO_2 concentrations and a longer presence.

The growing need for science-backed decision-making and an evolving market require that growers know the product in use and that they regularly consult researchers and manufacturers.

Moisture-absorbing material

Dr Fourie pointed out the limitations of moisture absorbing materials (MAMs) and their dependence on type. These are also passive rather than active absorbers. It is important that growers know what they want to achieve. "If growers want to reduce SO_2, the MAM has to be placed below the SO_2 sheet (directly on the grapes). If they want to reduce and trap moisture, it has to be placed above the SO_2 sheet."

Punnet type matters

The punnet type is equally important as part of packaging. In the absence of sufficient ventilation holes, punnets may act as a barrier between the SO_2 sheet and the grapes. An unvented top of a punnet may also act as a barrier, trapping warmish air from respiration, and leading to condensation and accumulation of free water. Understandably, there is a major difference between possible water accumulation and SO_2 levels when using clamshell punnets and open-top, heat-sealed punnets.

Dr Den Breeyen emphasised that clamshell punnets tend to trap moisture more than the open-top ones do. Like a human being swathed in plastic, the punnet may trap moisture in the table grapes amid all the layers of plastic packaging, especially when not sufficiently ventilated.

Humidity and temperature

Another objective was to identify optimal packaging combinations for decay control under different pre-packaging and post-harvest extremes, specifically assessing the impact of moisture and temperature abuse conditions on SO_2 treatment efficacy.

Dr Fourie is adamant that condensation is not the single most dangerous amplifier of SO_2 damage. Equally important considerations are the liner bag used – specifically the perforated area, punnet type, and the whole temperature chain management, avoiding detrimental temperature spikes.

The difference between transpiration and respiration became relevant, as they are the two main physiological processes of concern in the decline of post-harvest quality. Transpiration occurs when water vapour is released from the fruit surface, leading to wilting and stem desiccation. Respiration, on the other hand, is the post-harvest metabolic process where living berry tissues absorb oxygen and break down stored organic compounds – sugars and acids – to produce carbon dioxide, water and heat.

During their table-grape trials, Dr Fourie and his team also had to consider moisture levels and losses as part of quality management, besides the release and availability of SO_2. In non-perforated bags or less ventilated liners, the RH will be almost 100%. This reduces water loss and produces less shrivel and stem desiccation. In more ventilated bags the RH will be lower, increasing transpiration and moisture loss from the grapes – therefore, less dehydration of stems and weight loss.

Temperature, especially higher temperatures and temperature rising during storage, may influence the quality maintenance of table grapes. Dr Fourie explained that temperature spikes during cold storage relate to increased respiration. The increase in metabolic processes may differ in liners of varying perforated areas – this being why SO_2 release and packaging cannot be viewed separately.

Milestones and optimised guidelines

Dr Den Breeyen said that post-research, the researchers could make suggestions (rather than being too prescriptive) about what packaging combination growers could use under different pre- or post-harvest conditions. She noted that solutions need to be tailored for each specific scenario.

Dr Fourie observed that the final objective of this study would be the guidelines produced at the end of the project that needed to be reasonably broad. In summary, it should educate growers, highlight gaps in their current practices, and help them understand precisely where to apply this knowledge to optimise their packaging solutions.

Guidelines for optimal post-harvest packaging to limit decay in table grapes

This document provides practical recommendations for the post-harvest handling and packaging of table grapes, with the primary objective of reducing decay, extending storage life, and maintaining fruit quality during storage and transport. It is intended for growers, packhouse operators, exporters and supply chain stakeholders. The document also outlines the key factors influencing post-harvest deterioration in table grapes, including moisture loss, fungal decay (particularly *Botrytis cinerea*), temperature fluctuations, cultivar, and mechanical damage. It translates current scientific knowledge and industry best practices into actionable recommendations. Central to the guidelines is the optimisation of packaging combinations.

The guidelines address pre-cooling requirements and cold chain management, handling practices to minimise mechanical injury, as well as sustainability considerations, including recyclable and biodegradable packaging options.

The knowledge product includes decision-support tools, visual diagrams of packaging configurations, and comparative insights to help stakeholders choose the most suitable packaging strategies for their specific operational contexts.

Packaging and handling decisions should not be left to chance. They need to be guided by the precision of scientific evidence.

ACKNOWLEDGEMENTS

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Implementing institution:	ExperiCo - Agri-Research Solutions	**Author**	Imogen Campbell

phi **Project 06/2023 & 07/2023**

Ultra-low oxygen and nitric oxide treatment for pests in pome and stone fruit

Ozone fumigation as post-harvest phytosanitary treatment

Insect pests and fungal pathogens dictate the timing, level of investment, and scope of research for fumigation regimes, integration of new technologies, and cold treatment processes. If they are not mitigated according to the phytosanitary requirements and regulations in targeted export markets, access for the premium-quality fruit of South Africa will be significantly hindered.

The Post-Harvest Innovation (PHI) Programme and Hortgro partnered to co-fund two research projects in this regard. One focused on using ultra-low oxygen (ULO), with and without nitric oxide (NO), for alternative post-harvest treatment of pests and fungal pathogens in pome and stone fruit. The other, on ozone fumigation as a post-harvest phytosanitary treatment for insect pests and plant pathogens.

Regulatory restrictions have increased, fumigant maximum residue limits (MRLs) are becoming more restrictive (whilst chemical fumigants are being phased out), and evolving consumer demands require more sustainable production systems. These factors have collectively necessitated the evaluation of alternative phytosanitary interventions.

The phasing out of methyl bromide fumigation in key export markets has sparked a quest for suitable post-harvest treatments that are effective against a wide spectrum of pests and fungal pathogens. Dr Renate Smit (Hortgro PHYLA Manager and researcher) noted minimal chemical residue and maintained fruit quality as important prerequisites for the alternative treatments.

PHYLA, a phytosanitary research laboratory and insectary established by Hortgro in 2023, houses a small-scale ULO fumigation system that enables precise manipulation of oxygen, carbon dioxide, nitrogen, and NO concentrations.

Background and overall goal

To control key internal and external pests, and fungal pathogens that target South African pome and stone fruit, Dr Smit evaluated ULO atmospheres, with and without NO and in combination with cold storage, as alternative post-harvest treatments.

In a second project, she evaluated the efficacy of gaseous ozone fumigation as a post-harvest phytosanitary treatment for controlling selected insect pests and post-harvest fungal pathogens on pome fruit.

Ozone is a strong oxidizing agent that inflicts oxidative damage to the respiratory system of the insect. This causes the insect respiratory stress, cuticular damage and eventual death.

And ozone gas (O_3), with its well-documented antimicrobial properties, is used for surface and environmental sanitation in the food industry.

Its alignment with sustainability and residue-reduction goals makes ozone an ideal alternative in post-harvest applications. And international research further substantiates the efficacy of ozone fumigation for controlling post-harvest fungal pathogens on pome fruit, as well a s suppressing certain arthropod pests in stored commodities. As for protection during cold storage, ozone can oxidise ethylene to potentially retard ripening.

It makes sense to report on the two projects together, because both sought to identify alternative fumigation regimes that meet international phytosanitary requirements. Essentially, addressing the same need using two different avenues.

The insect pests targeted in the ULO research included the grain chinch bug and two-spotted red spider mite *(Tetranychus spp.)* – external pests –

and codling moth – an internal pest. And the targeted fungal pathogens were *Penicillium expansum*, *Penicillium digitatum*, *Botrytis cinerea* (sensitive and resistant strains), *Diaporthe ambigua* and *Lasiodiplodia theobromae*.

Targeted organisms in the ozone fumigation research were largely similar, with the addition of mealybug and the banded fruit weevil. The impact of ozone fumigation on fruit quality and ethylene dynamics during cold storage was also assessed.

Dr Smit emphasised the overall goal of complete insect pest mortality on the one hand and retained fruit quality on the other. Of equal importance, she added, are these pre-requisites for post-harvest phytosanitary treatment efficacy: cost-effectiveness, safety, and operational feasibility. However, these can only be achieved through ongoing research and development, which are crucial for continued entry of South African fruit into key international markets.

Methodology

A small-scale ULO fumigation system was designed and constructed for the ULO research to ensure precise manipulation of oxygen, carbon dioxide, nitrogen and nitric oxide concentrations – which was imperative. NO fumigation was conducted under hypoxic conditions (<30 ppm O_2) at concentrations ranging from 1–5% and exposure durations of 2–24 hours.

With pest mortality and retained fruit quality ranking high on the research radar, external pest mortality was assessed directly after treatment and cold storage, and egg viability and larval survival were monitored over time. The response of grain chinch bug (a targeted external pest in this research), for example, to various O_2 and CO_2 concentrations, at -0.5 °C can be seen in Table 1 below.

Mixing box to modify and measure gaseous composition in containers, e.g. oxygen, carbon dioxide and nitrogen levels. Fumigant and analyser can also be added to this system.

Regarding fruit quality for both the ULO and ozone treatments, the threshold of the fruit – across cultivars – for phytotoxic damage was a critical metric. Hence, fruit responses were evaluated using the quantitative approach of regression models, which were derived from central composite designs. Regression models produce data from spotting trends through analysis of relevant

Table 1: Exposure of grain chinch bug to different O_2 and CO_2 concentrations for 24 hours at -0.5 °C.

Treatment outline	Mean mortality and Standard error (SE)
Control (no modified atmosphere)	8.3 ± 6.0%
0.1% O_2 (balance nitrogen)	20 ± 4.3%
0.5% O_2 (balance nitrogen)	64 ± 6.3%
1.1% O_2 (balance nitrogen)	86 ± 3.7%
0.1% O_2 + 2.3% CO_2 (balance nitrogen)	56 ± 7.7%
0.5% O_2 + 2.3% CO_2 (balance nitrogen)	74 ± 3.5%
1.1% O_2 + 2.3% CO_2 (balance nitrogen)	94 ± 2.9%

relationships, providing vital information for predictive decision-making.

All fumigation experiments followed a defined sequence to distinguish screening, treatment and storage effects. First, insects and/or inoculated fruit were exposed to ULO or NO fumigation, either at ambient temperature or under cold conditions, depending on the objective.

For internal pest trials, Dr Smit and her research team allowed larvae to develop to the target instar inside fruit, at 25 °C, prior to treatment; fumigation was then conducted on the fruit, at 2 °C under hypoxic conditions, after which fruit were transferred to -0.5 °C to simulate commercial cold storage.

Post-treatment assessments were performed either immediately or after cold storage, with samples subsequently held at 20–25 °C for recovery, emergence or mortality evaluation. Ambient fumigation trials were used only as short-duration screening assays, whereas efficacy conclusions were based on treatments combined with cold storage. In the context of this research, an assay (or rather, a bioassay) tells us what the impact of a pest management regime is on the targeted pests.

In the ozone fumigation research, the team assessed the mortality of external pests immediately after treatment and cold storage, whereas egg viability and larval survival were monitored over time.

The effects of ozone fumigation on pathogen lesion development, insect pests, ethylene dynamics, and fruit quality were an important consideration. Why? This enabled the dual purpose of complete insect pest mortality and maintained fruit quality.

A disease severity index (DSI) was used to quantify disease severity. It integrated lesion incidence and lesion diameter and – importantly – provided a biologically meaningful metric for zero-inflated lesion data.

Findings

ULO and NO

ULO treatments alone, even when combined with cold storage, were insufficient to achieve effective control of two-spotted red spider mite adults or eggs. In contrast, grain chinch bug mortality increased under hypoxic conditions, particularly when moderate CO_2 levels were included. However, complete mortality required prolonged exposure or additional stress factors.

NO fumigation under low oxygen conditions was highly effective against motile insect stages. At relatively low NO concentrations and short exposure durations adult grain chinch bugs and adult red spider mites were completely controlled. NO also suppressed egg viability in red spider mites, although ovicidal efficacy remained limited. For codling moth – the internal pest – NO fumigation achieved high mortality of larvae. However, high NO concentrations and long exposure durations caused unacceptable phytotoxic damage in apples.

Fruit quality

Dr Smit and her research team found fruit quality responses to be highly cultivar- and concentration-dependent. The phytotoxic damage in apples, pears, and plums increased in tandem with an increasing NO concentration – particularly above 3% NO – whereas exposure duration played a secondary role. Lower NO concentrations were associated with minimal quality impacts but reduced insecticidal efficacy.

Ozone

Ozone fumigation was found to be capable of suppressing the growth of key post-harvest fungal pathogens, reduce red spider mite egg viability, and lower ethylene concentrations during storage without compromising pome-fruit quality. It showed limited efficacy against certain insect pests, which underscores two important factors: why defining target-specific treatment regimens must be prioritised, and why ozone fumigation should be viewed as part of an integrated post-harvest management strategy rather than a standalone insecticidal treatment.

Ethylene dynamics

Notably, ozone exposure reduced internal ethylene levels in the fruit. The team found this to be consistent with ozone-mediated oxidation of ethylene, and that it suggests a potential secondary benefit of ozone fumigation through modulation of ripening and senescence processes during storage.

Fruit quality

As mentioned earlier, the study proved that ozone can be applied safely without compromising fruit quality, all whilst providing measurable benefits in suppressing post-harvest fungal pathogens, reducing red spider mite egg viability, and lowering ethylene concentrations during cold storage.

Disease severity

The DSI recorded pathogen-dependent lesion development in pears, in response to ozone fumigation. For *Penicillium expansum* – an aggressive fungal pathogen – and a fungicide resistant strain of *Botrytis cinerea* the research team found that lesion incidence remained high across treatments. However, through weekly ozone exposure, complete suppression of lesions caused by the fungicide resistant *Botrytis* strain was achieved. *P expansum* recorded suppressive rather than curative effects for ozone fumigation, which merely altered lesion expansion. Non-resistant *Botrytis* did not produce lesions under any treatment, which confirms limited pathogenicity under the experimental conditions.

Apples showed lesion incidence that remained close to 100% across ozone regimes. Here, ozone effects were expressed primarily through changes in lesion severity rather than infection frequency. Short-duration ozone fumigation at 2 ppm, consistently produced lower DSI values in 'Granny Smith' apples compared with the control and continuous low-dose ozone treatments. Ongoing exposure to 500 ppb ozone was associated with larger lesions, suggesting a stress-mediated response without effective pathogen suppression.

Non-parametric statistical analyses (Kruskal-Wallis) showed no significant treatment effects on DSI values for pears or apples ($P > 0.05$). This reflects high biological variability and limited replication, which are typical in lesion development studies. Again, this reiterates ozone as a supplementary post-harvest tool rather than a standalone insecticidal treatment.

The ozone treatment appeared to be successful at low concentrations for the spore suspended strains. However, contamination of the plates with *Aspergillus niger* and *Rhizopus spp*. resulted in the masking of the effect of ozone on the target fungal pathogens (different concentrations) on treated plates.

And though – according to literature – higher concentrations are more effective, there is potential toxicity to humans and fruit that needs to be considered.

Required modifications

Effective commercial implementation will require lower NO concentrations that are applied over extended periods, improved fumigation termination protocols, and integration with cold storage or modified atmospheres.

Regarding ozone, pathogen assays presented challenges specific to contamination and inoculation variability. These have informed protocol modifications for future trials, like improved aseptic handling, laminar-flow inoculation, and enhanced cold-room sanitation procedures.

Potential outcomes

The data generated on the efficacy of both fumigation regimes for controlling post-harvest insect pests and fungal pathogens on pome and stone fruit will prove invaluable for the industry.

NO fumigation has been identified as a technically feasible and potentially cost-effective alternative. However, its efficacy and safety under commercial cold-storage conditions require further investigation.

Outcomes will be instrumental in the development of post-harvest sanitation and phytosanitary protocols that can be integrated into commercial cold-storage and packhouse operations.

And in the absence of industry guidelines or standard operating procedures for ozone use in post-harvest environments, industry role-players may look to these developed protocols.

Benefits for industry

ULO and NO

The ULO project provides new knowledge on the use of alternative fumigants, such as NO, to control pests whilst maintaining fruit quality. It also highlights the complexity of developing treatments for target pests that pertain to various commodities. Insights gained regarding NO fumigation will be used in other related projects at PHYLA.

Ozone

Regarding ozone, new knowledge has been uncovered on the application of gaseous ozone fumigation as a post-harvest phytosanitary and sanitation treatment for pome and stone fruit under South African storage conditions. Ozone provides measurable benefits in suppressing post-harvest fungal pathogens, reducing red spider mite egg viability, and lowering ethylene concentrations during cold storage.

The findings contribute to improved understanding of the role of ozone within post-harvest systems, particularly as a residue-free intervention that aligns with sustainability and reduced chemical input objectives.

Critically, a realistic framework for integrating ozone fumigation into existing post-harvest management strategies has also emerged through demonstration of efficacy against selected pests and fungal pathogens, and identification of limitations against more tolerant insect species.

The outcomes also support the potential use of ozone as a supplementary tool to:

- enhance post-harvest sanitation in the industry
- reduce environmental spore loads
- mitigate phytosanitary risks that relate to export consignments.

As for ethylene concentrations, their observed reduction further substantiates possible secondary benefits through delayed ripening and extended storage life. These may contribute to maintaining fruit quality during long-distance transport.

Once assessed, the ultimate effect of ozone on insect pests, fungal pathogens, fruit quality, and ethylene dynamics will serve as a vital guide for data generation. In turn, this will help drive fact-based decision-making around the potential integration of ozone fumigation into commercial post-harvest regimes.

The way forward

In research, findings are hardly ever a conclusion. They tend to unlock a new layer of questions. Owing to the new findings below, the two research projects have been extended by one year.

ULO

In pest suppression, phytotoxic risk to the fruit must be considered. Hence, future research will prioritise very low NO concentrations (≤0.001%), applied over extended periods.

Response-surface models were used to determine the most optimal combinations in the pest management regime, for maximum overall efficacy. However, additional replication and expanded datasets are required to improve their reliability and predictive power.

Fumigation termination must be improved and venting protocols established to prevent oxygen contamination and subsequent NO formation.

Another identified area of improvement is the control of egg and internal life stages. Hence, further exploration of integrated treatment strategies that combine NO, cold storage, and controlled atmospheres should be further explored.

Sensory evaluation (taste and aroma) – a key indicator in consumer preference analysis – will be included in future studies. This is bound to strengthen market penetration and retention and help detect potential fermentation-related quality defects.

Ozone

Since grain chinch bugs showed no mortality under the initial tested ozone regimes, Leander Engelbrecht (PhD student) is currently testing a different treatment regime for this pest.

Trials are also being conducted by a research team to examine the effect of ozone on mealybugs (eggs and adults), and its potential damaging effect on egg emergence. Additionally, trials with an ozone treatment of 500 ppb (continuous treatment) are currently underway.

Also in the pipeline, are trials to refine treatment regimes, improve pathogen assay control, and confirm efficacy against additional insect pests.

And the effects on the resistant *Botrytis* strain indicated a strong biological response that warrants further investigation with increased replication.

A second round of trials will be conducted on lugs, under increased control and with modifications to protocol, to assess the effect of different ozone concentrations.

Regarding cold storage, data sets were incomplete, which hindered statistical comparisons. Therefore, apple cultivar trials were set to be repeated during the 2026 season.

Overall, both projects strengthen the evidence base required for informed decision-making regarding adoption of the alternative fumigants in commercial packhouses and cold-storage facilities. Continued optimisation and validation will be instrumental to confirm operational parameters and economic feasibility, but the results indicate clear potential value for the South African pome and stone fruit industry.

Nitrogen generating system holding tank. It can be used in cold rooms or a mixing box to lower oxygen levels for fumigation.

Modified Atmosphere Packaging (MAP) bags that help to determine the effects of modified atmosphere packaging on insect mortality and fruit quality

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Special note: *Emilia Arendse, Simonay Claasen, Meagan Hendricks and Lee-Zaan Scheepers found employment due to their project participation.*

Project 10/2023

Improving the structural integrity of cartons for the export of fynbos

Viable solutions to a costly fynbos-carton problem

The expertise of Stellenbosch University's Prof. Corné Coetzee was enlisted to find viable solutions to a costly problem facing the fynbos industry.

In the 1980s, the band Living in a Box released an eponymous song whose refrain – "Am I living in a box? (Living) Am I living in a cardboard box?" – reflects the reality of South Africa's premium fynbos stems, which spend up to half of their post-harvest lifespan in paperboard boxes during sea transit.

Sea freight is cost-effective, reducing rates by approximately 50–60% compared to air freight. It is also suitable for some species, cultivars and selections of the hardy, cut-flower fynbos products. But this means that these products spend up to 29 days at sea in ventilated, corrugated paperboard cartons.

Some of these cartons did, in fact, collapse en route to their final destination. This setback is also prevalent in air-freight shipments, where freight skids typically do not have the rectangular, stable configuration of sea freight pallets. An assessment of local exporters and European importers showed that approximately 5–13% of all shipments had failed cartons, including both sea- and air-freighted products. This was the multi-million-rand problem identified by Cape Flora SA (CFSA) that had a profound economic and reputational impact on growers.

Despite the standardisation of the geometric size of the boxes used for export, the paperboard used is up to the manufacturer and can range from grammage to Kraft (strong and durable), or recycled (weaker) to the fluting size and the number of layers comprising the carton.

The need to establish minimum specifications for carton structural strength was, therefore, identified and supported by industry stakeholders. This set in motion a process to develop a carton with an improved design, or to establish minimum carton-strength standards in the industry.

CFSA approached Prof. Corné Coetzee – Professor: Granular Materials Research Group at Stellenbosch University's Department of Mechanical and Mechatronic Engineering. And Tiaan Cronjé, a master's student at the time, was assigned to assist.

Failure mechanism identified

An image was produced that depicted the damaged boxes upon arrival in the Netherlands. The cause of the problem was not immediately apparent during the initial inspection. The duo proceeded to design a laboratory set-up that would replicate the transport conditions, only including those deemed important in their estimation.

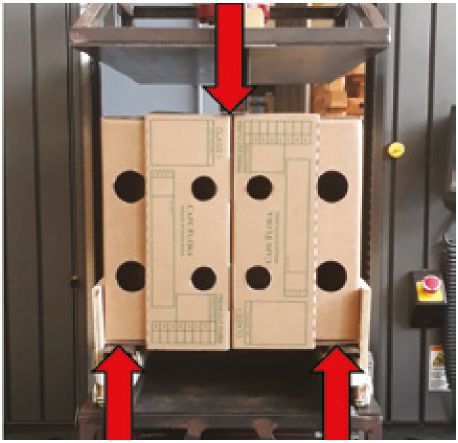
Then an entire pallet was put through repeated lateral acceleration and deceleration tests. It then became evident that they were dealing with the same failure in the well-controlled laboratory environment, as seen in the image – mostly in the lower part of the pallet.

Coetzee observed, "We knew that, at least we are replicating the conditions, because our box was failing in the same manner." However, bulging was not the cause of the failure mechanism. He asserted that the issue was the lateral movement, or shear failure, rather than compression failure.

Through this process, he identified the dominant failure mechanism in an existing carton design (S22 Superstack) widely used in sea freight exports. Coetzee explained, "It's a combination of the box's dimensions and its overall design. The lid doesn't extend all the way to the bottom and because the tray alone lacks sufficient strength, the carton, as a whole, fails during transport."

A new test for science

Coetzee explained that conditioning is always part of any box testing. Whilst box compression tests were the standard, he proposed use of a new one that they developed, the box shear test (BST).



Box shear test.

For the BST, instead of using one box, two were used and box compression tests were implemented, albeit laterally. To do so, careful support of the boxes was imperative and these were firmly pressed down in the middle. This simple, yet effective test produced the same kind of failure. "Not only was it new for the industry or for these kinds of boxes, it was new for science."

Although box compression and box shear tests were used on the newly designed boxes, they were also validated in a pallet stack under repeated acceleration and deceleration conditions. It is proposed that all new boxes for this application are subjected to all these tests, and when a box meets all the minimum load requirements, is could successfully be used for this specific application.

An unexpected challenge

Coetzee didn't expect for them to have to undertake the project without a manufacturing partner, or any form of collaboration. Although the boxes could be designed, construction was not possible due to a lack of the necessary equipment and materials.

At the very least, they needed a partner to cut the box according to their design. After they approached Mpact Corrugated, the company came on board and was willing to cut the prototypes for them. However, months passed before the prototypes were ready for them to do the testing. Notwithstanding delays, it all worked out well in the end.

Field tests

Coetzee provided details about the field experiment conducted. A trip to the airport was arranged, where boxes were loaded onto a pallet and placed on a truck. Thereafter, Cronjé and the driver drove around for 30 minutes to replicate the real-world conditions that boxes may be subjected to on a pallet during transportation. All measurements were recorded to ensure that the set-up in the laboratory simulated conditions experienced in transit.

The results of the field test were then used to ensure that the acceleration produced in the laboratory tests simulated truck conditions. Not only did they measure the forces on individual boxes in the laboratory, but also stability of the whole pallet. Coetzee added that these were interlinked: If the box failed or started to fail, then the whole pallet became unstable.

A device used to measure the loads on a palletised carton.

Additionally, the more unstable the boxes are, the more movement there is on the pallet, which increases the impact on the boxes. This is the reason, he concluded, that it was imperative to consider both when designing a box.

He explained that the boxes were then conditioned. There was a conditioning chamber in the adjacent building, where Cronjé would take the boxes and condition them for 24 or 48 hours, according to a specified standard related mainly to exposure to a set relative humidity.

This would lead to moisture absorption by the carton. "As quickly as possible, [the student had] to bring them over to the engineering faculty and do the test within 20–30 minutes. "

Coetzee noted that some of the results were inexplicable. During cyclic load testing, it appeared as though the boxes were recovering some of their strength, which could be attributed to changes in the humidity.

Limited scope

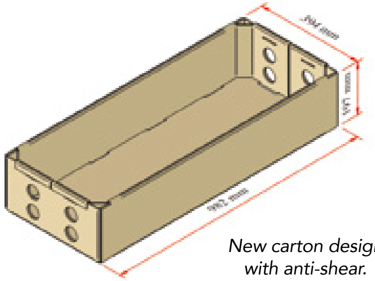
Importantly, Coetzee explained that the presence and placement of ventilation holes could influence individual box performance, as well as the stability of the whole pallet. Therefore, it was imperative that one considered box performance, pallet stability and cooling holistically.

However, in this study, the scope was limited to assessing the structural strength of the box. And because CFSA had not indicated any concerns around cooling, they kept the total area of ventilation the same.

Results

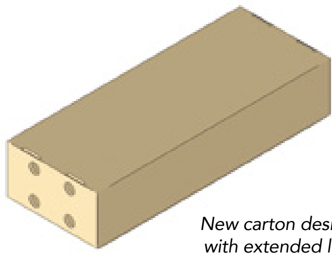
In the end, four new cartons were designed, namely the edge vent tray and lid, the extended lid with a standard tray, the anti-shear tray with a standard lid, and the mailer box. Findings showed that all, except the edge vent tray and lid, performed better than the industry S22 Superstack carton and complied with the minimum structural strength specifications for cartons.

The fourth design (mailer box) was a novel product that eliminated the need for a separate tray and lid. It also enabled a more stable brick stacking compared to the S22 Superstack, which could only be column stacked on a pallet.



New carton design with anti-shear.

Referring to the anti-shear box design, Coetzee shared a surprising anecdote. Having already developed more complex, improved solutions, he asked the student to simply "extend the lid all the way down the tray and test that." And it was the request for the final design that turned out to be a stroke of genius. "I didn't really expect that to be the best solution. It's the simplest one."



New carton design with extended lid.

After the significant finding regarding the extended-lid box, he said that the actual cost per carton would increase. Essentially, each carton needed additional paperboard to accommodate the extended lid. Stakeholders were faced with a crucial decision: either carry the extra cost associated with this new design or bear the brunt of losses endured due to damage in transit.

These findings were presented to CFSA and producers and submitted to an international journal. The team looks forward to receiving feedback.

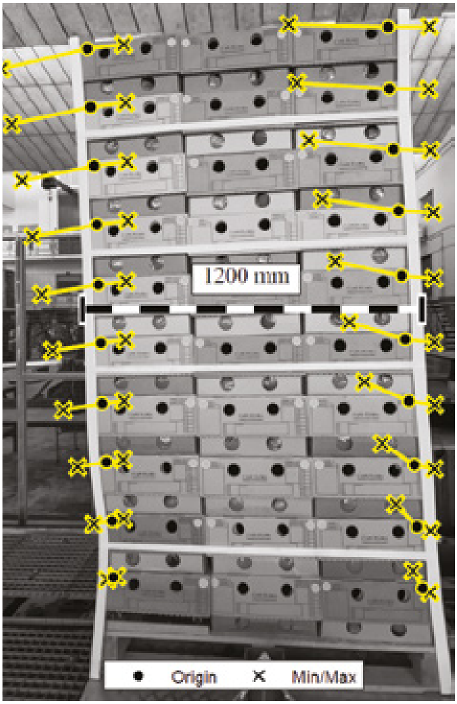
The way forward

Coetzee confirmed that a document would be produced reflecting the proposed minimum standard.

When quizzed about the possibility of using an alternative material to paperboard, he remarked, "I am hesitant to say there won't be something different to paperboard, but at this point in time, paper-board is the best: low-cost, relatively high-strength, and it can easily be recycled."

The team has extended the project, as they agree that it warrants further testing. Incorporating more carton types and enlisting additional manufacturers should help to facilitate imminent industry-wide implementation of paperboard cartons.

Proteas packed for export.



Paper board cartons.

The Post-Harvest Innovation (PHI) Programme has played an integral role in enabling the cut-flower fynbos industry to explore viable, research-based solutions to a costly fynbos problem – a challenge that impinges on South Africa's market competitiveness and reputation.

ACKNOWLEDGEMENTS

Project lead: Prof. Corné Coetzee

Implementing institution: Stellenbosch University

Involved institution: Cape Flora SA (CFSA)

Participating student: Tiaan Cronjé (MSc: Mechanical Engineering)

Author: Imogen Campbell

phi Project 11/2023

A quest to develop an efficient organic avocado treatment using nanotechnology for managing post-harvest fruit quality

Nanotechnology – paving the way for post-harvest fruit quality

Could edible coating and plant-based Zinc Oxide (ZnO) nanoparticles be the answer to challenges regarding post-harvest fruit quality retention in avocados?

Prof. Samson Tesfay from the Horticultural Sciences Department at the University of KwaZulu-Natal has spent years researching nanotechnology. He boldly advocates for its use in managing post-harvest fruit quality.

As the regulatory environment grows more rigorous, so must the tactics to mitigate pathological and physiological disorders in fruit. This includes local legislation, like the recent regulatory updates in the Fertilizer, Farm Feeds, Agricultural Remedies and Stock Remedies Act 36 of 1947, on regulations relating to agricultural remedies (promulgated in August 2023).

But effective disease mitigation requires ongoing research and coordinated funding.

Prof. Tesfay led a project that sought an organic post-harvest treatment to retain the fruit quality of avocados. The project was co-funded by the Post-Harvest Innovation (PHI) Programme and the South African Subtropical Growers' Association (Subtrop).

His research explored the effects of an edible Moringa oleifera-based coating and plant-based Zinc Oxide (ZnO) nanoparticles, as well as carboxyl methyl cellulose (CMC), as a post-harvest avocado treatment to be used in place of Prochloraz (a post-harvest chemical treatment widely used previously in packhouses where avocados are packed). Prochloraz has been found to be detrimental to the environment and is a known endocrine disruptor.

Some context

The post-harvest losses linked to biotic factors in avocado cultivars are caused by two major post-harvest diseases – anthracnose and stem-end rot. Respectively, these culprits can inflict up to 80% and 70% of post-harvest fruit loss if fruit are not treated.

The EU Standing Committee on Plants, Animals, Food and Feed (SCOPAFF) has introduced a new maximum residue limit (MRL) import tolerance for Prochloraz that makes the concentration too low for product implementation and effectiveness.

As for competing in the fierce international fruit trade, the export-oriented avocado industry of South Africa continues to rely on an efficient logistics system to get fruit to international destinations with its quality intact.

Objectives

Prof. Tesfay's project objectives were clear: 1) Finding an alternative treatment that is ecologically friendly and recognised in the field of food safety, 2) Reducing fruit loss caused by pathological and physiological disorders, 3) Continuing to expand the efficacy of the edible coating, and 4) Registering and commercialising the product.

Non-chemical post-harvest treatments for avocados aim to reduce the amount of fruit lost due to post-harvest disease development. These treatments prioritise quality, texture retention, flavour and aesthetics.

Project rationale

It makes sense to prioritise alternative disease control mechanisms that are both ecologically friendly and recognised in the field of food safety. Moisture and gas control are imperative in the post-harvest care of avocados.

The edible coating slows down respiration so that the fruit does not "breathe itself into oblivion". It also prevents fruit weight loss – a critical market requirement.

ZnO nanoparticles deal a rupturing physical punch to the cell walls of fungi and bacteria that cause rot.

And ozone is an effective antimicrobial agent that is naturally found in the stratosphere. It provides tent-like protection from UV radiation.

Important considerations

To be effective, post-harvest disease mitigation strategies must take various factors into account.

For avocados, these include the fact that:

- repeated treatment using the same fungicide or active component may lead to disease resistance and fungicide residue deposition
- ethylene causes accelerated ripening, softening, and internal discolouration in avocados
- avocados are sensitive to post-harvest diseases like anthracnose (Colletotrichum spp.) and stem-end rot
- avocados are susceptible to chilling injury, and develop skin pitting and darkening, grey pulp, vascular browning, and off-odours.

A favourable outcome

The findings of Prof. Tesfay's research champion the use of *Moringa oleifera*-based leaf extracts-ZnO nanoparticles and CMC as a post-harvest edible coating treatment to preserve avocado fruit quality.

And the CMC-plant extracts-ZnO nanoparticles present the potential to reduce avocados' susceptibility to external chilling injury if made commercially available to the industry.

His work proved that the organic product has the capacity to significantly suppress the pathogens responsible for the fungal diseases of anthracnose and stem-end rot.

Evidence-based decision-making is important to help preserve the post-harvest quality and aesthetic integrity of South African avocados destined for export. This could help maintain South Africa's status as a major global exporter of avocados.

What is Moringa?

- The Moringa oleifera plant is a super-nutritious natural preservative and biostimulant. It also has a range of functional properties.

As a natural biostimulant for fruit trees, Moringa:

- enhances growth
- stimulates higher yields and quality
- is abiotic-stress resistant
- reduces fruit drop.

In post-harvest treatment Moringa:

- delays ripening.

In pest and disease resistance Moringa:

- acts as a natural fungicide and pesticide, reducing reliance on chemical inputs.

Plant-based bio-fungicides

- Reduce environmental pollution
- Limit the impact on non-target organisms
- Improve soil health
- Lower greenhouse gas emissions
- Increase food safety
- Reduce the risk of pesticide resistance.

ACKNOWLEDGEMENTS

Project lead: Prof. Samson Tesfay

Implementing institution: University of KwaZulu-Natal

Involved institution: South African Subtropical Growers' Association (Subtrop).

Participating students:
Nomzamo Dyantyi (MSc: Agriculture),
Wendy S'phesihle Mthimkhulu (MSc: Agriculture);
Nqobile Victoria Bhengu (Honours: Horticultural Science),
Londeka Mkhize (Honours: Horticultural Science)
Thembelani Mzizi (Honours: Horticultural Science).

Author: Catherine Milward-Bridges

phi **Project 03/2023**

Generation of a Berry Cracking Index for the South African table grape gene bank

R&D – industry lifeline for growers navigating berry cracking

The viability of the South African fruit industry hinges heavily on research and development. It needs funding and support.

Right from project inception, industry role-players in the South African fruit industry demonstrated a collaborative approach to research and development (R&D), circumventing a universal challenge faced by researchers who often lack funding to implement their findings.

The Post-Harvest Innovation (PHI) Programme and the South African Table Grape Industry (SATI) initiated and co-funded a project dubbed, "Generation of a berry cracking index for the South African table grape gene bank". This is one of three such collaborative projects between the two entities that have been conducted under PHI-5.

A problem to solve

The project was focused on berry cracking, which demands a robust mitigation strategy. From it emanated the development of an index that can offer vital insights to breeders when selecting parents and when evaluating cultivars.

Berry cracking typically occurs due to the physical failure of the waxy layer of the skin of the grape berry. This is a major concern for table grape growers worldwide, and certainly those in the South African export-oriented table grape industry.

This physiological disorder, which is intersectional in nature, has its origins in a complex junction of environmental, physiological and genetic factors. The physical failure of the berry cuticle is triggered by a combination of factors, including the structure and composition of the fruit surface, turgor, Abscisic acid (ABA) levels, and water absorption. Turgor is the pressure exerted by fluid against the cell wall, which reflects in the sugar content of the berry flesh.

Getting to work

To commence the co-funded project, Dr Justin Lashbrooke of Stellenbosch University's Department of Genetics headed up a team, including PhD student Robin Nicole Bosman, who was tasked with implementing an optimised assay.

The successful implementation of the harvesting and data acquisition work was vital to the success of the task at hand.

The laboratory procedure was implemented across the South African table grape gene bank, resulting in the developed index for cracking resistance or susceptibility.

The team could measure up to 220 different table grape cultivars for their skin elasticity, which was then used as a proxy for measuring their susceptibility to cracking. The objective findings from this exercise allowed the researchers to rank cultivars based on cracking resistance.

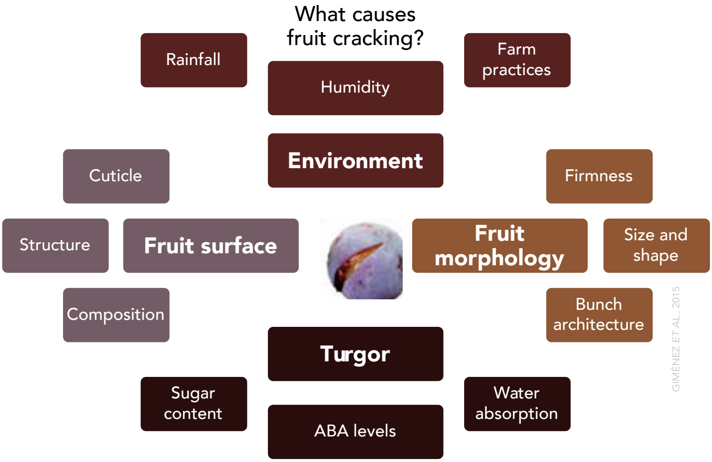
Pre-harvest vigilance

The rationale behind the co-funded project was to gain an understanding of berry cracking at field level.

Long before table grapes are harvested, opportunistic pathogens can enter the berries through surface cracks and, under specific conditions, latent infections may become active. In some instances, this manifests as berry cracking. So, the reality is that observable post-harvest berry cracking can originate in pre-harvest conditions.

Cultivar choice

To breed the next generation of cultivars, breeders must select the correct parent material.



Therefore, the referenced index is a useful tool in objectively scoring cultivars for their resistance to cracking.

Berry cracking is also under genetic control, as it has been established that some cultivars are more susceptible to cracking than others. Plus, it has become evident that there is a clear correlation between skin elasticity and crack resistance.

The research outcome provides growers with concrete knowledge of the extent of cultivar susceptibility to cracking, as well as a uniform point of reference. This is a breakthrough in providing the right tools for growers' planning around cultivation and breeding programmes.

Waste not, want not

Table grape growers can ill afford the fruit loss related to berry cracking – not to mention the potential related economic losses.

Quality being a key focus in the production of South African table grapes, effective mitigation of cracking improves the export potential and possibly even the shelf-life of table grapes.

Down the line, the findings of this research project can be instrumental in bringing about significant savings for proactive growers. In turn, this will help ensure financial stability at farm level and enable these growers to continue to provide much-needed jobs.

And the pre-harvest component of the research can help table grape growers manage their vineyards more effectively to avoid berry cracking later on.

Out with the old

In an ever-evolving industry, producing different results demands a new way of thinking. This places immense pressure on growers for a paradigm shift.

They face an increasingly competitive global market landscape. And research such as this, which presents new approaches to address long-standing challenges, plays a key role in ensuring industry sustainability.

The outcomes of this co-funded project align with industry disease mitigation objectives and signal a promising future. However, further research is required to fully maximise this significant groundwork.

ACKNOWLEDGEMENTS

Project lead: Dr Justin Lashbrooke

Implementing institution: Stellenbosch University

Involved institution: South African Table Grape Industry (SATI)

Participating student: Robin Nicole Bosman (PhD: Wine Biotechnology)

Author: Imogen Campbell

phi Project 14/2023

Non-chemical control of post-harvest diseases in avocado

Fungal pathogens constantly wage a pre- and post-harvest war on avocados, infecting fruit from the pigeon-egg stage in the orchard, but emerging as destructive diseases only after the fruit are harvested and ripened.

Avocado growers are faced with significant post-harvest losses due to fungal diseases that cause severe infections, affecting 40-70% of the fruit. For many years, the avocado industry has depended on a single fungicide, Prochloraz, to control these destructive fungi. However, the reduction by the European Union (EU) in allowable Prochloraz residues to 0.03 ppm on imported avocados, meant that urgent intervention was needed.

The Post-Harvest Innovation (PHI) Programme and the South African Avocado Growers' Association (SAAGA) partnered to co-fund a research project focused on the non-chemical control of post-harvest diseases in avocado.

For Professor Emeritus Mark Laing of the Plant Pathology Department at the University of KwaZulu-Natal (UKZN), this disease-management vision had already been sparked in 2009 when he anticipated that the fungi infecting avocado fruit would eventually develop resistance to fungicide, as well as the growing risk that consumers would demand the phasing out of systemic fungicides applied to the fruit that they eat.

Background

Avocados endure an onslaught from several fungal pathogens in the orchards, which mostly initiate latent pre-harvest infections in young fruit.

Cunningly, fungal pathogens like anthracnose infect fruit asymptomatically. They create a disease-free façade by remaining motionless inside the fruit. Then they pounce at the ripening phase when antifungal compounds like phenols that protect the unripe fruit are no longer present. The fungal damage occurs only once the fruit have ripened, making it unsalvageable and disappointing for consumers.

It was becoming clear that dependence on systemic, curative fungicides like *Prochloraz* would no longer be a viable option. On 31 December 2023, the EU dropped the maximum residue limit (MRL) of Prochloraz in avocado fruit so low – 0.03 ppm – that it would no longer work, effectively banning it in fruit destined for the EU markets.

Project objectives

Profs Laing and Kwasi Sackey Yobo, and the participating students had their work cut out – 30-70% (R9 billion worth) of avocado losses had to be mitigated with a robust combat strategy.

Their primary goals were to:

- develop a pre-harvest biocontrol agent to stop fruit being infected by the initial infectious phase of post-harvest pathogens in the orchard
- optimise rapid Hot Water Treatments (rHWT) for avocado packhouses
- test Ultraviolet-C as an alternative technology to rHWT
- screen a range of edible food film products for the preventative control of post-harvest diseases in avocados.

Combat strategy

They devised a three-pronged combat strategy – pre-harvest in the orchard, and post-harvest for both the packhouse and once the fruit were ready to leave the packhouse.

In the orchard

First, they needed to treat the fruit pre-harvest in the orchard, using a biocontrol agent to build protection into young fruit against being infected by post-harvest pathogens.

Symbiosis

An important part of this pre-harvest phase in the combat strategy is the symbiotic relationship between the tree and the endophytic biocontrol fungi.

Endophytes infect the skin of leaves, shoots, flowers, and fruit.

They come in peace, for a reciprocal, long-term union with the tree. During infection, the endophyte communicates biochemically with the host plant (i.e., the avocado tree), declaring its friendly status. The deal is that the skin of the fruit feeds them and in return, they control pathogenic fungi that attack the fruit skin.

So, Prof. Laing and his team set out to find suitable endophytic fungi to lay the groundwork for establishment of a symbiotic relationship. This approach has proven successful with cacao in Brazil and to protect Acacia mangium in Australia, reported Prof. Laing.

To date, the team has isolated several biocontrol strains of Trichoderma that can infect the skin of avocado leaves and fruit. These strains also kill the main fungal pathogens attacking avocado fruit. Greenhouse and field trials remain to be completed in 2026.

In the packhouse

Most avocados arrive in the packhouse having already been infected by key post-harvest fungal pathogens.

In the absence of Prochloraz, the harvested fruit would need to undergo a rapid Hot Water Treatment (rHWT) or ultraviolet (UV) treatment to kill latent infections by post-harvest fungi that cause anthracnose and stem-end rot, in particular.

rapid Hot Water Treatment (rHWT)

Speed, efficiency and the correct temperature are crucial when applying the rHWT method – an Israeli brainchild. Like a vaccination, rHWT triggers the immune system of the fruit, resulting in the release of phytoalexins into the fruit. These are natural fungicides that kill latent fungi in the skin.

Prof. Laing and his team devised the perfect "recipe": 15–30 seconds at a temperature range of 56–60°C. With this treatment, the fruit is undamaged and the immune system is triggered. However, if there is an "overdose", say a hot water treatment for one minute, the fruit would be injured, the immune system disabled, and the post-harvest fungi would infect the fruit 100%.

Notwithstanding Prof. Laing's 20 years of dedicated rHWT research, the superior efficiency of UV-C light necessitated a pivot to developing this technology for avocado treatments.

UV-C light treatment

Researchers have found that UV light at key wavelengths, especially UV-C, triggers the release of natural fungicides. This is the same reaction as rHWT in fruit and vegetables. The result is a strong internal disease resistance reaction, enhanced nutrient content (such as antioxidants), slowed climacteric ripening, and extended shelf life.

Pulsed Light treatment – a new technology – is an alternative to UV-C. In a single concentrated pulse of light lasting only one second, the unit generates light in a wide range of wavelengths, from visible light to the far end of UV light. This technology appears to be extremely powerful and may be more effective than UV-C. One of these units is being investigated by Profs Laing and Yobo at UKZN.

When fruit is ready to leave the packhouse

Prof. Laing and his team explored two options to ensure that the fruit have a protective layer that prevents infection during the shipping and retail process.

Biocontrol yeast

Certain biocontrol yeasts can control the germination and growth of post-harvest pathogens on fruit. The yeasts also replicate themselves and colonise wounds.

The team has found excellent strains that are viable biocontrol agents to fully protect fruit from the main pathogens of avocado.

The commercialisation and registration of a biocontrol yeast strain require further extensive testing, formulation, large-scale production, and storage tests, followed by a lengthy registration process. Hence, this is a long-term solution.

Protective coating

As a preventative measure, it would be useful to be able to apply an antifungal fruit coating against subsequent infections during storage, transport, ripening, the retail process, and consumers' handling of the fruit. Such a product would need to be a safe food coating, labelled as a "generally regarded as safe" (GRAS) product.

Prof. Laing and his team identified gum Arabic and chitosan as ideal GRAS products for post-harvest decay control. Gum Arabic comes from acacia trees, whereas chitosan is a natural, biodegradable polymer derived from shellfish.

They conducted numerous trials to determine the ideal concentrations and settled on 12–15% gum Arabic as being the most effective for the gum by itself. However, growers will have difficulty mixing this much gum Arabic with water, as it makes the fruit sticky to the touch and a reduced concentration of gum Arabic requires the addition of an antifungal GRAS compound like chitosan or potassium silicate. The team is working on further trials to be able to produce a viable product composition as a preventative treatment for avocados.

Detecting infected fruit

Simphiwe Tseku (an MSc student) worked on a project to see if it was possible to detect diseased fruit using a small, portable, low-powered, battery-operated near-infrared (NIR) scanner. The calibration models are excellent for detecting diseased flesh directly, using a fruit that has been cut open. It can also detect diseased flesh through the skin of an avocado, but not very accurately.

NIR technology has already been successfully implemented to grade fruit in several new packhouses in the South African avocado industry.

Detecting ripeness

At the same time, Tseku tested the NIR unit for its ability to detect ripe fruit. It did this reasonably well but struggled to penetrate the thick skin of Hass avocado fruit. Again, a high-powered NIR scanner could penetrate the skin better, and give an accurate ripeness classing to send fruit into the correct bins for different ripeness classes.

Detecting maturity

Deciding when avocado fruit is mature is a difficult task for avocado farmers. Mature fruit will ripen into a creamy edible fruit, whereas immature fruit will never ripen properly and stay watery and tasteless. The NIR unit worked well in estimating ripeness, using dry matter content as the reference measurement of maturity. Using the portable scanner, this technology could be used by avocado farmers to make decisions on whether to pick avocado fruit in an orchard.

Portable, low-powered, battery-operated near-infrared (NIR) scanner.

BENEFITS SNAPSHOT				
	rapid Hot Water Treatment	UV Light Treatment	Biocontrol Yeast	Gum Arabic
Superior energy efficiency	✗	✓	N/a	N/a
As effective as systemic fungicides	✓	✓	Possibly, once a suitable agent has been tried and tested.	✓ (but has complex mixing requirements)
No fruit damage	✓	✓	✓	✓
Slows climacteric ripening	✓	✓	N/a	N/a
No residue	✓	✓	✓	(the residue is an intentional protective measure)
No required registration	✓	✓	✗	✓
Can be implemented industry-wide	✓ (pending equipment installation)	✓	✓ (only once it is registered)	✓

Most of the aspects of this project have been completed, pending a few additional experiments.

Avocado growers and the industry stand to benefit significantly from the outputs of this research.

ACKNOWLEDGEMENTS

Researchers: Prof. Mark Laing, Prof. Kwasi Sackey Yobo

Implementing institution: University of KwaZulu-Natal

Involved institution: South African Avocado Growers' Association (SAAGA)

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Sfundo Ndlazi (MSc: Plant Pathology)
Simphiwe Tseku (MSc: Plant Pathology)
Londeka Mkhize (MSc: Plant Pathology)
Onosizo Asimdumise Zondi (MSc: Plant Pathology)

Author: Catherine Milward-Bridges

phi Project 09/2023

Export readiness training for PDI's in the Cape Flora industry

Cultivating the right environment for transformation in the fynbos industry

Cape Flora SA's Karien Bezuidenhout sheds light on inclusive growth in the local fynbos industry.

Karien Bezuidenhout, General Manager at Cape Flora SA (CFSA), recently stated, "[South Africa] may not be the only cultivating country, but I would say we are the pioneers of the fynbos industry. It was South Africa that took the plants from nature, started breeding and cultivating them, and then figured out how to make an agricultural crop from it."

So the indigenous Cape flora cut-flower industry took root in the 1970s. And today, South Africa exports millions of stems that reach significant markets in Europe and the Middle and Far East annually. Other role-players in the market include Australia, New Zealand, Ecuador and Portugal. Gratifyingly, local expertise is still sought after, drawing keen interest from abroad.

CFSA's membership comprises those involved in harvesting fynbos flowers from the veld (20%), and the rest who are actively involved in fynbos cultivation. Though many emerging fynbos farmers are proficient in critical farming skills, a knowledge gap was identified specifically regarding post-harvest handling, processes involved with export, and adherence to international standards.

The right training for the job

Soon the need for extra training and capacity building among previously disadvantaged individuals (PDIs) covering export readiness was identified. To kick-start the process, CFSA communicated its intent to assist emerging fynbos farmers, and soon interested parties heeded the call. And so a journey began to nurture members' field of dreams born out of opportunity. "The greatest challenge, I would say, is cultivating the right environment," said Bezuidenhout.

Over the course of three years, workshops in the Western Cape were run in Piketberg, George and Baardskeerdersbos. The format worked well, as experienced farmers and stakeholders could engage in critical fynbos-industry-related discussions. Participants received templates to populate with their own data and, immediately, theory became practice and could readily be incorporated into their own businesses.

PHI workshop in Piketberg, July 2023.

"I think we covered the topics quite well," observed Bezuidenhout. "There are many courses out there that teach the basic principles of post-harvest physiology. But this one is specific to fynbos, which makes it an asset." She added that one of the presenters, Prof. Marius Huysamer, is a fynbos farmer himself who knows the ins and outs of fynbos farming and is able to translate the theory into farming practices.

Wilhelm Rabe of AgriSMART SA, an implementing partner, contributed considerable technical expertise drawn from his years as a former fynbos farmer, as well as a wealth of experience gained in related industries. He is also known to have a heart for people, with true compassion, noted Bezuidenhout, all of which came through in the training.

"I must say, what is also very useful is to have our Transformation Board member, Jacky Goliath, on board." She was an invaluable resource as a presenter "because she had been through the process, knew all the pitfalls, and knows what it takes to take that next step," reflected Bezuidenhout.

An amazing crop of people

There are many success stories in this industry, she said, but if asked to highlight someone, these individuals come to mind: The husband-and-wife duo at 34 Degrees South and the Mxokozeli siblings from Elim.

Fergus Ontong and Beverley Joseph, a couple from George in the Southern Cape, are breaking new ground. Both are graduates with prior farming experience, albeit in hops cultivation. These budding farmers are now in possession of their own land and determined to make a success of fynbos farming.

As part of CFSA's support for developing growers, they were selected to go on a study tour to the Netherlands in 2023. Bezuidenhout explained, "Their business was organised and registered. They were already producing flowers and had the right level of doing business." Upon return and having observed the entire value chain, Ontong developed their very own application (app) to keep track of orders, personifying the pioneering spirit of old in a modern context.

IPM ESSEN, a trade show in Germany, followed in January 2025 where Ontong promoted their own flowers. And now that 34 Degrees South exports, he also volunteered to represent CFSA at the show. "He's not just looking after himself, he is willing to give back to the industry as well," beamed Bezuidenhout.

Fergus Ontong, proudly exhibiting flowers at IPM ESSEN in January 2025.

Fundamentally, small-scale farmers in Africa face significant hurdles when attempting to export. In order to get the requisite volumes, aggregation of growers is often employed. Bezuidenhout confirmed that in Ontong and Joseph's case, they were producing, as well as buying from other growers. "They have their own packhouse and they interact with the growers around them. CFSA also linked them up with Wesgro, the Western Cape Government's agency focused on export." This demonstrates what can be achieved when opportunities are seized with open arms.

Justice, Phosiza and Thandiwe, the three Mxokozeli siblings from Elim in the Overberg, have also exhibited immense fortitude. Bezuidenhout confirmed that they were leasing land, Riverside Farm, from the state and had "started their journey [with CFSA] quite a few years ago, attending the training in the Southern Cape." Formally trained at Elsenburg Agricultural Training Institute, they had the basic knowledge of agriculture, she says, but attending this course gave them vital tools that also helped them understand export dynamics.

The three Mxokozeli siblings from Elim in the Overberg. Clockwise from the top: Justice, Phosiza and Thandiwe.

"At the beginning of 2025, they said, 'We are ready. Our flowers are coming into production. We are on a good track.'" Excitingly, their flowers were incorporated into the award-winning display at the Chelsea Flower Show in London. And by year's end, it was Thandiwe's turn to go to the Netherlands where she attended the International Floriculture Trade Fair (IFTF), with support from CFSA. Her exposure to this floral wonderland should help to pave the way to export readiness, and they are poised to do so by 2026/7, under the Iqhude brand. Bezuidenhout highlighted their thankfulness and eagerness to learn, which have stood them in good stead.

Cultivating success

Bezuidenhout aptly sums up the role of CFSA in these transformation stories: "We link them with the right people at the right time. And we help them get the right mindset." Related to this is Bezuidenhout and Goliath's hands-on approach. Once a year, they pay an official visit to each individual project, imparting invaluable input along the way. A technical consultant, paid for by CFSA, is also dispatched every six weeks to ensure that the right process is implemented at the appropriate time.

It is clear that the investment delivered a huge return for all involved. CFSA prides itself on having open communication where ongoing interaction between the growers and this association is encouraged. In turn, members perceive the organisation as approachable and feel free to ask for help, volunteer, and signal when they are ready to level up. By accessing CFSA's nurturing support, these members have found that the world is, indeed, their oyster.

As for the future, Bezuidenhout asserted that they would continue to do what they have always done: "Innovate, innovate, innovate. As an association, we innovate to see how we can better help our farmers do business and become more efficient and productive." She added that the farmers themselves were innovative, always figuring out better ways of doing things.

That the industry is transforming is unmistakable. Bezuidenhout emphasised that it was difficult for small associations to access funding and that this transformation project would not have been possible without the support of the Post-Harvest Innovation (PHI) Programme and the Fresh Produce Exporters' Forum (FPEF).

ACKNOWLEDGEMENTS

Project Lead:	Wilhelm Rabe	**Author:**	Imogen Campbell
Implementing institution:	AgriSMART SA		
Involved institution:	Cape Flora SA (CFSA)		

phi Project 01/2023

Pre-harvest sanitation on table grapes

Sanitisers and biologicals as part of your supplementary spray-programme arsenal

This research project, which commenced in 2022, shows that sanitisers can supplement growers' spray programmes and be an effective part of their arsenal against pathogens and decay.

In table grape production, the principle "a stitch in time saves nine" is especially relevant, as pre-harvest practices such as canopy management and vineyard sanitation have a direct and significant impact on post-harvest quality, storability and decay management.

However, when it comes to managing pre-harvest decay, effective control strategies are not always clear. Along with physical removal of symptomatic berries from vineyard floors and bunches, sanitisers and biologicals can be incorporated into spray programmes to support post-harvest success.

To better assist growers with this, a study was initiated to determine the efficacy of integrated pre-harvest sanitation practices for improving decay control in the table grape industry.

It was jointly funded by the South African Table Grape Industry (SATI) and the Post-Harvest Innovation (PHI) Programme. The research team comprised Dr Johan Fourie, Inge Block and Daniël Viljoen of ExperiCo.

First, sanitisers and bio-fungicides were identified by the industry. Eight were used during in-vitro testing against specific post-harvest pathogens, namely *Alternaria alternata*, *Botrytis cinerea* and *Penicillium expansum*. Varying product concentrations (1X, 2X and 4X the recommended dose) were employed, whilst the most effective products were tested, using three different spore loads, i.e. (5 x 104, 1 x105 and 2 x 105 spores /mL and at different contact periods (5, 10, 15 and 30 minutes).

Ultimately, only four of the most effective products (90–100% efficacy) were selected for vineyard trials. Sanitisers and biologicals were incorporated into the existing fungicidal and insecticidal spray programmes of commercial vineyards in the Western Cape that exhibited a history of decay problems. These trials, as well as berry removal, were supervised throughout. Moreover, the table-grape cultivars, 'IFG Ten', 'Sugra 35' and 'Crimson Seedless', were evaluated during this trial.

The use of sanitisers to bolster a preventative arsenal

Table grapes are thin-skinned and, therefore, susceptible to decay caused by post-harvest pathogens. These pathogens thrive under fluctuating weather conditions, which can lead to berry cracking – an ideal entry point for infection. Consequently, increased decay is often observed when excessive rain is followed by high temperatures. Mitigation strategies for post-harvest disorders such as berry drop, weight loss, stem browning and fungal decay are therefore essential.

Sanitisers generally leave minimal residue that can be defined as trace amounts of fungicide or chemical compounds that remain on or in the fruit after application. It thus makes them a suitable option for expanding the fungicide toolbox for use on table grapes. As a result, researchers set out to identify sanitisers and biologicals with suitable active ingredients to do much of the heavy lifting.

Sanitisers, bio-fungicides and fungicides

Block clarified that a sanitiser is any surface disinfectant. It kills on contact and is primarily used in pack-houses to sanitise equipment and ensure worker hygiene. In the laboratory, it was found to be effective, killing up to 99.9% of bacteria or mould, subject to the conditions. The sanitiser's role is to decrease the incidence of spore inoculum.

A bio-fungicide is basically a biological, i.e. a living organism that finds itself in competition with a fungus: both compete for the same thing but the bio-fungicide outgrows it.

A fungicide is an agricultural remedy – a chemical or biological substance – used to prevent, control or eliminate fungal infections, pathogens or spores that damage plants, crops and agricultural commodities (CropLife South Africa).

What separates the above-mentioned products are, firstly, mode of action and, secondly, active ingredients (actives). Block stated that the mode of action for sanitisers is more general in type, whilst in fungicides, it specifically targets the fungus and is registered as such.

The role of active ingredients

The products classified overall as sanitisers and biologicals had a combination of the active ingredients (see Table 1).

Table 1: Active ingredients in classified sanitisers and biologicals

Product	Ingredient
Bio-fungicide	Ascorbic acid and bioflavonoids
Biologicals	Bacteria *(Bacillus spp.)* and one a fungus *(Trichoderma sp.)*
Disinfectant	Hypochlorous acid and sodium chloride-based sanitisers
Sanitisers	Peracetic acid and hydrogen peroxide among others.

The effectiveness of sanitisers depends on certain present actives. The whole point of sanitation is inoculum load reduction, and to keep it as low as possible until the time of harvest.

Fungicides, on the other hand, have a longer lifespan. But growers are limited; they may only use a certain number of actives in a season, and use is prescribed by international regulations. This is known as the pre-harvest interval or withholding period, which is the number of days required between the last spray and harvest.

It is critical that growers adhere to this, otherwise they risk exceeding the maximum residue limit (MRL), which is the highest level of pesticide residue legally permitted in food. Exceedance jeopardises market access.

Dwell time also needs to be considered. Dr Fourie emphasised that for both the fungicide and sanitiser, the duration of contact with the fruit's surface is important. He said that it was more so for a sanitiser than a fungicide, because sometimes the latter had mobility and could penetrate, leaving a residue.

A pre-harvest focus

A clear distinction needs to be made between vineyard management and sanitation. Day-to-day vineyard practices are aimed at maintaining vineyard health. These also act to optimise fruit quality. In the long run, these practices are designed to make life less favourable for a fungus, through mitigation like canopy management.

On the other hand, sanitation refers to practices specifically aimed at the removal and destruction of infected berries, mummified fruit, and vineyard debris, along with equipment hygiene, in order to reduce pathogen inoculum.

Infection increases just before harvest, as the fruit matures. Dr Fourie noted, "It's due to the natural process of senescence." He explained that the closer to harvest, the more growers would need to reduce spore loads on the fruit surface. They try to harvest just before that optimal stage.

So, in a sense, growers' harvesting interrupts the maturing process of table grapes, to get the fruit to the consumer in good condition.

This is where MRLs really come into play. Growers' dilemma is that they must know what actives they need to combat the problems that they are experiencing in the field, but they are also faced with fungicide resistance or losing sensitivity. Sanitisers and biological products supplement growers' fungicide arsenal through ongoing reduction of inoculum loads.

Biggest challenge and the way forward

Field trials in the 2023/4 season did not reveal significant treatment effects in terms of the following:

- reduction in decay;
- loose or split berries;
- pedicel, receptacle and rachis condition; and
- berry firmness.

Block observed, "I think the biggest challenge of this project was environmental." The laboratory is tightly controlled. Close communication with growers ensured timeous application of products and the trials were supervised throughout. But other factors, notably moisture, played a significant role. Clearly, contact time within the laboratory environment can be controlled, but how does one do that in the field?

Block said that she believed the way forward was continued testing. In the future, this could entail focusing on areas of high inoculum zones or disease pressure. The four products that performed very poorly during in-vitro testing had failed by a considerable margin, she said, and they would not be reconsidered for future trials.

Conclusion

As many researchers can attest, promising results in a controlled environment must be thoroughly assessed before they can be relied upon in real-world conditions. The same can be said about this project: after promising in-vitro trials where some products were 100% effective against *Botrytis*, *Alternaria* and *Penicillium*, field testing did not replicate the glowing results under field conditions. Environmental factors had, in all probability, influenced this discrepancy, especially the temperature and wetness duration.

Research findings show that sanitisers must be used in conjunction with fungicidal and insecticidal sprays, not as a stand-alone product. Dr Fourie encapsulates the new knowledge acquired: "Sanitisers must be seen as supplementary to fungicides used."

During the trials, farmers continued with their own fungicide spray programmes, whilst the sanitisers and biologicals were applied at intervals before harvest. However, the researchers observed that a hypochlorous and sodium chloride-based sanitiser, as well as peracetic acid and hydrogen peroxide-based sanitiser, generally reduced decay during the in-vitro and field trials.

Ultimately, users should not expect sanitisers to kill as effectively out in the field. Sanitisers cannot replace fungicides. This knowledge is novel and is encouraged as an additional sanitation practice.

AUTUMNCRISP® orchard.

ACKNOWLEDGEMENTS

Project team: Daniël Viljoen, Dr Johan Fourie, Inge Block

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phi Project 16/2023

Botrytis cinerea as a pathogen of blueberries in South Africa

Vital research to understand *Botrytis cinerea* – a major challenge in South African blueberry production

When the field pathogen, *Botrytis cinerea*, was put under the proverbial microscope and monitored from the field to the packhouse, vital findings shed light.

The South African blueberry industry has invested substantially in managing the pre- and post-harvest impact of fungal, bacterial and viral diseases. *Botrytis cinerea*, with its tell-tale grey mould on blueberries, has caused blueberry producers untold headaches.

Though blueberries are one of South Africa's fastest growing horticultural crops, they are non-indigenous to the country. Factors such as international demand, profitability and job creation have driven increased local blueberry production. Conversely, industry growth has highlighted a dearth of research in terms of production and disease management.

Hence, the Post-Harvest Innovation (PHI) Programme and Berries ZA partnered to co-fund this multi-pronged research project. Prof. Karin Jacobs of the Department of Microbiology at Stellenbosch University led the project. Her field of expertise spans microbial ecology and fungal taxonomy.

The project, divided into various sub-projects, aimed to generate new knowledge and provide foundational data on the prevalence, community structure and fungicide resistance of the *Botrytis* pathogen.

It covered this necrotrophic pathogen from field to packhouse, as well as the rise of fungicide resistance in blueberries. Integrated pest management (IPM) and rapid identification of *Botrytis* in the field, the role of honeybees as a potential source of inoculum, as well as the role of *Cladosporium spp*. and *Penicillium spp*. in blueberry plants, were all components of the research.

Several outcomes were envisaged for this project, all focused on the understanding, control and management of *Botrytis* in the South African blueberry industry.

Botrytis cinerea and blueberry production in South Africa

Botrytis is the bane of several agricultural sectors where the pathogen's wide-ranging effects have led to significant yield losses and export quality issues, especially in grape and berry production.

A few berry crops are commercially produced in South Africa, but blueberries comprise the largest proportion of this industry. Agriculturally important blueberry varieties are native to North America, where it snows, disrupting the growing season. South Africa's location means that it does not have a snow cycle, which translates into a longer growing season, but also a pathogen that grows through local winters.

The Western Cape is a major producing area, accounting for more than 60% of the country's total production. As such, research for this project was conducted on three provincial farms in Napier, Paarl and Stellenbosch.

In the field

Botrytis cinerea as a field pathogen and the rise in fungicide resistance

The focus was two-fold:

1. It analysed disease and inoculum profiles. This is defined as a comprehensive assessment of the biological material introduced into a new environment. These profiles were then analysed in relation to environmental factors, namely temperature, humidity and rainfall.
2. It also assessed fungicide resistance across the production region in the Western Cape.

Over 800 strains were isolated, and a sub-sample was screened for fungicide resistance. It became clear that:

a. Airborne inoculum levels of *Botrytis* in orchards fluctuate throughout the growing seasons, but levels markedly increased during flowering and harvest months.

b. The data indicated a rise in fungicide resistance, with only a limited number of fungicides remaining fully effective in controlling the pathogen.

Prof. Jacobs explained, "Resistance to these fungicides is quite problematic, particularly because there are now a number of European Union rules that limit pesticide residues and limitations on the type of pesticides that they can use. The arsenal of fungicides that they have available to them is getting smaller, and the pathogen is building up resistance." The dichotomy is clear, but in addition, fungicides are also expensive.

Crucial to the planning of fungicide applications is gaining an understanding of the inoculum concentrations over a growing season, and the level of fungicide resistance in this fungus.

How *Botrytis* moves from the field

Understanding the role of phytopathogens in the mycobiome (fungal communities) of blueberry-foraging Western Cape honeybees *(Apis mellifera capensis)*

Honeybees play a pivotal role in agricultural ecosystems, and in South Africa, for example, they are essential pollinators for crops like blueberries. The honeybee microbiome – a superorganism comprising diverse bacteria, fungi and other microbes – has been identified as a key component of bee health and resilience.

Yet, despite their ecological importance, honeybee populations are in widespread decline. Factors that contribute to their demise include habitat loss, nutritional stress, pathogen exposure, and pesticide contamination.

In addition, though the bacterial microbiome has been well researched, the role of fungi remains underexplored, particularly in their interactions with bees. Phytopathogenic fungi like *Botrytis* and *Cladosporium spp*. could substantially impact honeybee health – as plant pathogens or as potentially beneficial symbionts.

Prof. Jacobs highlighted that the industry at large may not have been aware of the significance of the honeybee microbiome and the bee's role as a potential vector. "What is really interesting is that the bee currently used – the Cape honeybee – is not ideal for the pollination of a blueberry flower. Solitary or wild bees have been shown to be more efficient, although honeybees may be easier to manage on commercial orchards."

She also observed that honeybees performed poorly when foraging on blueberry pollen. Therefore, reduced lifespans are observed and producers can lose a lot of bees.

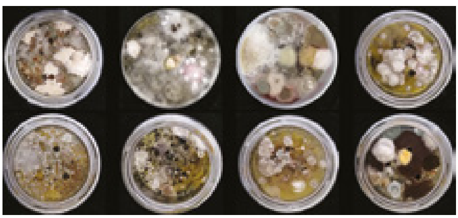
Additionally, "The honeybees have to remain for long periods of time on a pollen source that is sub-optimal. And what the bees then do to improve nutrition is they collect fungi."

This phenomenon has also been observed elsewhere in the world. "It has been noticed that bees will collect fungal spores, because they can provide vital amino acids. Blueberry pollen lacks some of the critical amino acids that bees require for their growth and development."

"And they can supplement that by collecting fungal spores. Now, a bee doesn't know what the difference between a good fungus and a bad fungus is. So, if there's a lot of *Botrytis* around, they will collect it. And we found they also collected a genus called *Cladosporium*, a common environmental fungus."

In a controlled experiment, some of the blueberry pollen was spiked with fungi and the number of visits to the food source was tracked. Prof. Jacobs said that it was "To see if the bees would preferentially go to that food source with or without the fungus. And they seemed to like the one with the fungus more."

The researchers followed that up by looking at their immune response. This aspect of the research, said Prof. Jacobs, was particularly important for growers using commercial beehives for pollination.



Fungi from bees:
Results showing the fungi carried on the bodies of bees.

Conclusion

- Bees can unintentionally carry and collect pathogens like *Botrytis* and *Cladosporium* spp. in resource-limited environments.
- Additionally, these pathogens can be dispersed from diseased plants to healthy plants.
- Honeybees also showed a preference for fungal-inoculated pollen, especially *C. cladosporioides.*

Back to the field

Developing a mycorrhizal product for use in blueberry orchards.

In this part of the project, blueberry roots were collected and screened for fungal associations. Some 56 fungal strains were isolated and identified.

Overall, blueberry orchards in the Western Cape have been shown to host a rich and active root-associated fungal community that can be attributed to natural soil conditions and farming practices.

From field to packhouse

Integrated pest management

Botrytis spores move from the field to the packhouse on berries that are infected, or have spores on them. The testing of indoor air quality in packhouses is generally not conducted, with airborne assessments typically excluded from standard protocols.

Prof. Jacobs made special mention of the pristine nature of the selected packhouses at the beginning of the season. Air sampling and swabs were used to sample data to assess the spread of *Botrytis*. Observational data collection was carried out from early July to early December 2024. Sampling was done twice a month during the packing season and one sample per site was taken post-sanitation, but before packing as a control.

This was done for the researchers to gain a better understanding of the transfer of pathogens from the field to the packhouse, facilitating the use of appropriate sanitation solutions.

Extensive data on the isolation of fungal pathogens from blueberries during harvest and throughout the cold chain was generated. The project also measured and enumerated airborne spores within packhouse environments.

The presence of *Botrytis* seemed to differ among packhouses and there were fluctuations in general fungal counts within a packhouse. These increased numbers were mostly attributed to *Cladosporium* and *Penicillium spp*. The data identified that main packing areas had accumulated a high load of fungal spores throughout the packing season. The overarching aim then became to correlate this high fungal spore load to the post-harvest disease incidence in packed fruit.

So, weekly air samples were taken in August/September. Some 300 processed berries were used, sourced from packhouses in Paarl and Stellenbosch, that had been identified for this aspect of the research. The fruit – kept at room temperature for a week or two – was then tracked and evaluated. A correlation between fungal spore counts and disease incidence were found.

The controlled stress assay using these berries showed that more than 80% of fruit remained asymptomatic. However, Botrytis was identified as the predominant cause of post-harvest disease.

Initially, it was thought that the high spore load in the main room could be attributed to a high volume of human activity and fruit movement. But further observation led to the deduction that the fruit appears to be the main carrier.

Prof. Jacobs commented, "As soon as the season began, there was a massive increase in fungal spores in those environments, but that was not the main concern – it was that we picked up high levels of the genus *Cladosporium*." This sub-project was the gateway to another one within this overarching project where *Cladosporium* was investigated in more detail.

Still in the packhouse

Rapid identification of *Botrytis cinerea* and determining if it grows at refrigerating temperatures.

The overarching aim of this part of the project was:

- To provide a fungal inoculant
- To produce a complete checklist of fungal diseases on blueberry plants.

At the outset, a method to rapidly identify *Botrytis* was developed using loop-mediated isothermal amplification (LAMP) primers, designed for *Botrytis* specificity and optimised for polymerase chain reaction (PCR) reactions. PCR is a highly sensitive molecular technique used to detect the presence of pathogen-specific DNA sequences. Several sets were developed to optimise the reaction. However, the method proved to be inconsistent as a result of low DNA template concentrations from the berries.

Next, researchers considered the immunological detection of *Botrytis*, using the BC-12.CA4 monoclonal antibody (Mab). However, as Mab was specifically designed to detect antigens on growing mycelia, the presence of *Botrytis cinerea conidia* could not be confirmed. Furthermore, it still required a PCR verification step, which had already proven unreliable.

More research followed, using qPCR, which was more reliable than immunological assays and conventional PCR for the detection of Botrytis on blueberries. This method is currently being optimised. The key objectives were an easier, faster method of detection of Botrytis, which can be used to monitor Botrytis levels on berries in the packhouse.

In the packhouse

A packhouse pathogen profile of *Cladosporium, Penicillium* and *Botrytis cinerea.*

Blueberries are susceptible to mechanical damage and infectious diseases caused by fungi. Locally, the fungal genera *Cladosporium*, *Penicillium* and *Botrytis* have been identified as prominent in South African packhouses.

Two-fold aim:

- Investigate the role of the *Cladosporium*, *Penicillium* and *Botrytis* species in post-harvest blueberry spoilage in South African packhouses
- Assess the influence of temperature on the growth of these species.

The following objectives were used to achieve the aim above:

1. Identification of packhouse isolates

First, researchers obtained pure cultures from previously isolated fungal cultures. Then they sequenced and phylogenetically analysed the isolates. This was for classification and evolutionary relationship determination purposes.

Thereafter, DNA was extracted from each isolate and primers used to amplify specific gene regions, selected according to the pre-determined genus of each isolate. The amplified regions were sequenced, followed by species identification – performed using phylogenetic analyses.

2. Pathogenicity assessment of isolates

Firstly, the researchers determined whether isolated *Cladosporium, Penicillium* and *Botrytis* packhouse strains infected blueberries under controlled conditions using inoculation assays.

Secondly, they performed inoculation assays under respective temperatures – 4°C, 16°C, 20°C and 35°C – to determine the influence of temperature on pathogen growth.

Thirdly, they determined the symptoms of these fungi in blueberries throughout their infection cycle. They then quantified the infection grade.

Lastly, there was re-isolation of disease-causing isolates from blueberry inoculation assays. Overall, these findings suggest that certain strains may be pathogenic under specific environmental conditions. It also underscored the importance of effective temperature management in mitigating post-harvest losses.

3. Health risk evaluation of isolates

The last of the three objectives was to determine the risk of the identified species to human health, specifically in relation to employee-safety working conditions. Available literature was used as a basis for this, aligning with the "One Health" framework, which is a holistic approach that integrates human, animal and environmental health.

Prof. Jacobs explained two concerns about the data, "The one was that *Cladosporium* was present in high levels that could potentially contribute to post-harvest disease. We also picked up some four or five different post-harvest pathogens in quite high numbers in those packhouses. *Cladosporium*, we also know, has detrimental effects on humans."

Importantly, she added that *Cladosporium* is known to exacerbate upper respiratory tract problems, even triggering asthma. "So, at high levels, it is a problematic group of organisms."

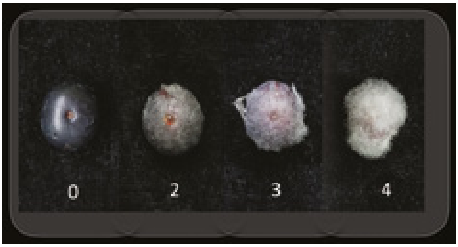
Efficacy of *Trichoderma* as a biocontrol agent dispersed by bees against *Botrytis cinerea.*

The fundamental outcomes of the initial project led to an additional project, which was undertaken to evaluate the efficacy of honeybees and the dissemination of *Trichoderma spp.* as a biocontrol agent.

The latter shows promise as a biocontrol agent, but effective delivery methods are needed. Honeybees can act as vectors for targeted delivery of *Trichoderma* spores to blueberry flowers, enhancing biocontrol and reducing reliance on chemical fungicides.

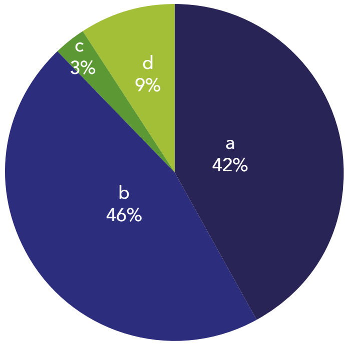
Summary of tangible outcomes for industry:

- Airborne studies have highlighted the specific location and movement of *Botrytis* in the packhouse. It should help with fungicide and sanitation practices.
- An online database of fungal pathogens on blueberry plants was initiated, and a field guide to common blueberry diseases in South Africa is being developed.
- The findings included the first report of pathogens on blueberries and other crops in South Africa, and the first report of potential *Trichoderma atroviride* pathogenicity on blueberries, particularly in packhouses.
- New knowledge has been generated – honeybees can act as vectors of phytopathogenic fungi.
- The findings identified key post-harvest pathogens, confirmed the importance of cold storage in suppressing disease, and highlighted potential human health risks to support improved monitoring practices.



Levels of infection:
Average pathogenicity scores after inoculated blueberries had been incubated for 5 days. The severity of the rot was scored using a scale of 0 to 4.

Sources from which *Botrytis* isolates were collected



Summary of the sources from which Botrytis isolates (n = 85) were collected during the survey of blueberry orchards in the Western Cape province of South Africa, including
a *diseased flowers 42%*
b *diseased berries 46%*
c *diseased leaves 3%*
d *diseased buds 9%*

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phi Project 4/2023

Internal browning of 'Cripps Pink' apples – focusing on unanswered questions

In 2026, the apple industry celebrated 364 years of growth. But chronology and experience are no match for physiological disorders – in this case, internal browning (IB).

The disorder has been the bane of the 'Cripps Pink' apple cultivar, especially considering its prominence in the Pink Lady® programme.

So, the Post-Harvest Innovation (PHI) Programme and Hortgro co-funded a research project that sought to address unanswered questions regarding IB of 'Cripps Pink' apples.

Dr Elke Crouch, Senior Lecturer in the Department of Horticultural Sciences at Stellenbosch University, led the research project.

A bit of context

IB is a physiological disorder that typically develops after long-term storage. It reduces marketable yield and threatens brand reputation, as an IB incidence of only <1% is accepted per consignment at export destinations (Fourie, 2003). Pink Lady® SA has set this margin at 0%.

Brown internal fruit flesh, with a firm consistency, is characteristic of IB. However, the disorder is often not detectable from simply looking at the intact fruit.

There are two main types of browning in 'Cripps Pink' strains. Diffuse browning (DB) affects the flesh from just below the peel, evenly to the inside, without impacting the vascular bundles. Radial browning (RD) is concentrated around the vascular bundles. And combination browning (CB) incorporates both RD and DB.

Research in other countries has shown that DB is triggered during harvesting seasons with cooler growing temperatures, and that RD is found in warmer climates. In 2010, Dr Crouch and her research team proved that, in South Africa, 90% of all browning was due to DB. And they later found it to relate to storage temperatures of -0.5°C. RD in South Africa is very seasonal and although levels were a lot lower in 2010, not knowing the sensitivity of the season currently makes it more difficult to manage.

To learn how to effectively manage IB in 'Cripps Pink' apples – particularly RD – Dr Crouch and her team had to go back to the orchard. Because it is in the pre-harvest phase that the potential for RD develops. Currently, DB is generally well managed in the post-harvest phase.

Dr Crouch highlighted the multi-factorial nature of IB as a key take-away for the research team, and cited contributing factors like pre-harvest temperatures, orchard factors and canopy position, as well as post-harvest storage technologies.

"I love the research process – getting to know the why behind what we observe," she enthused.

In the research, physiological maturity (rather than storage technique) emerged as the main driver of susceptibility. Over-maturity at harvest pre-disposes apples to IB, noted Dr Crouch. Therefore, she added, the stage of maturity at harvest is one of the most critical factors to consider.

Also worth noting is the fact that starch breakdown in apples is a key maturity indicator that has a direct link to increased physiological disorders like DB and CB during storage.

DB develops from chilling injury at -0.5 °C, over-maturity, or both (Butler 2015; Crouch et al. 2015; James 2007). However, RD, which is seasonal and seemingly pre-disposed by pre-harvest factors, requires ongoing study. It mainly affects the smaller fruit that are located on the inside of the canopy, which could be linked to their cell density, antioxidant status, or carbon assimilation.

Unlike RD, DB can be induced by rapid cooling and extended cold storage.

What was the goal?

Dr Crouch and her research team aimed to assess the effects of pre-harvest temperature and orchard factors (especially the rate of ripening) on IB. They wanted to investigate the effect of canopy position on IB incidence and associated fruit quality features. Plus, they aimed to evaluate the efficacy of dynamic controlled atmosphere-chlorophyll fluorescence (DCA-CF) storage alongside controlled atmosphere (CA) storage, in reducing IB after long-term storage. The team also attempted a prediction of the disorder, but further work is needed in this area.

The modus operandi

Pre-determined factors were examined to achieve the project goal.

Orchard factors and temperature

In assessing the effects of pre-harvest temperature on IB, orchard factors and temperature during fruit development were key data.

Temperature data from 85 orchards were collected, across four consecutive seasons (2021 to 2024) in the Western Cape and the Eastern Cape.

Ripening rate

To determine the ripening rate, 20 apples per orchard were harvested weekly, half-arm length into the canopy, from four to six weeks before the predicted harvest date for each orchard.

This was an important precursor to the fruit being evaluated for quality and disorders in relation to pre-harvest temperature patterns.

On the optimum harvest date, 300 apples were harvested per orchard.

They were then treated with 1-methylcyclopropene (1-MCP) and underwent CA storage for nine months at -0.5 °C (the low temperature was to make sure that browning does occur), then six weeks in regular atmosphere (RA) at -0.5 °C (simulating shipping and stock rolling overseas), and seven days at 20 °C.

Multivariate analyses, comprising principal component analysis (PCA), multiple factor analysis (MFA), correlations and cluster analysis, were used to make sense of detected associations between pre-harvest temperature conditions, fruit maturity, and defect incidence across developmental stages. Overall, these showed weak but informative associations within a highly variable, multifactorial system.

Importantly, there seems to be a link between ripening rate and IB incidence. The highest DB incidence was associated with a faster rate in ground colour breakdown, increase in mass, and faster starch breakdown, from approximately six weeks before harvest. High RB incidence was associated with the slowest increase in circumference, mass, seed colour change, and starch breakdown from approximately six weeks before harvest. It seems that these two browning types have opposite drivers.

Canopy position

Could canopy position influence IB incidence and associated fruit quality attributes?

To find out, the research team interrogated the possibility that the delayed harvesting of 'Cripps Pink' apples in the inner canopy (to allow more time for red colour development) may result in advanced fruit maturity and a related increase in IB susceptibility. They harvested fruit from different canopy positions on targeted days, across four seasons, on four commercial farms in South Africa.

After the referenced 1-MCP treatment, CA and RA storage, selected analyses and statistical modelling techniques were employed. From these, the team was able to evaluate the effects of canopy treatments on fruit maturity, quality and defect development before storage; after CA storage and simulated shipping and during shelf life. They were also able to identify maturity variables associated with post-shelf-life defects and assess the predictive value of pre-storage measurements.

Findings

The team concluded that effective management of IB requires an integrated orchard-to-storage approach. This includes monitoring pre-harvest temperatures, accounting for orchard factors, separating fruit by canopy position, and applying strict maturity indexing before low-oxygen storage to maintain Pink Lady® quality.

Pre-harvest temperature and orchard factors

The study identified a link between the incidence of higher RD and high yielding orchards, warmer [growing day degree hours (GDH)] fruit development 0–22 weeks after full bloom, cooler ripening conditions (GDH) 0–4 weeks before harvest, and higher titratable acidity (TA) 0.7% at harvest. Inside canopy fruit were smaller, had less blush colour and more RD, especially in season where fruit were not harvested over-mature.

DB was prevalent in seasons with higher maximum and average temperatures growing degree days (GDD) during 0–4 weeks before harvest – confirming its impact on a faster ripening rate before harvest. It was also associated with low blush and low TA. Amid high DB incidence the TA percentage was lower, with a lower blush percentage.

And with CB there was an identified link to seedling vigour and fruit size (larger fruit). But with no clear temperature effects.

Ripening rate

This factor affected DB and RD differently.

A link was detected between DB incidence and fruit growth slope (increased rate in mass and height). Fruit with higher DB also related to a faster rate in ground colour breakdown and starch breakdown rate. Warmer pre-harvest temperatures were found to accelerate starch breakdown. This may have impacted carbohydrate reserves, which play a vital role in fruit development. The one facilitates the critical transition from immaturity to an edible fruit, and the other fuels the metabolism of the fruit during storage. Fruit from a longer growing season appeared to break down starch slower.

RB incidence, on the other hand, was associated with the slowest increase in circumference, mass, seed colour change, and starch breakdown. Notably, in fruit with high RB there were no CO_2 cavities in the core and very low CO_2 core and CO_2 flesh browning. However, fruit with high CB also had higher CO_2 cavities in the core and high CO_2 core and CO_2 flesh browning.

Canopy position

The research team found blush development to be consistently highest in the first commercial harvest of outer canopy fruit, across seasons. And despite the second delayed harvests of both inside and outside canopy fruit to improve colour, blush colour coverage remained below 40% in fruit located in the second harvest inside canopy (Ramos, 2026).

Knowing what the fruit maturity is before storage, emerged as a critical factor for IB management. This was particularly important regarding long-term storage at low oxygen. Unrefrigerated transport from the field during hot conditions, and a delay before storage, were identified as key contributors to the advancement in fruit that were harvested at optimum to beyond optimal maturity for such storage.

Notably, inner canopy fruit showed acute susceptibility to RD, superficial and peduncular scald, and higher total IB. But no correlation was found between DB and CB and canopy position.

So, yes, canopy position does influence fruit quality and post-harvest disorder risk. It should, therefore, be considered in post-harvest management strategies.

As for recommended best practices for growers' more effective management of IB, they include cognisance of canopy structure, harvesting at the right maturity, minimising transport time, measuring maturity before fruit enters cold storage, storing fruit according to inside and outside canopy fruit, using a targeted cold storage type (CA or RA), and applying step-down cooling.

"Looking back on where we've come from since 2010, the collaboration between researchers and industry players has produced huge changes in the handling of Pink Lady® fruit,"

reflected Dr Crouch.

phi Project 4/2023

Internal browning of 'Cripps Pink' apples – focusing on relevant risks

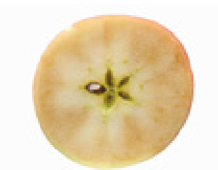
Confronting the multi-factorial risks of internal browning in 'Cripps Pink'

Effective risk mitigation is imperative when it comes to managing internal browning (IB), a physiological disorder that breaks down the structure of an apple. Whilst it constitutes a chemical reaction (oxidation), IB is also a symptom of membrane and cellular failure.

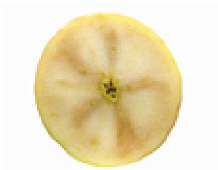
This disorder is well managed within the South African apple industry through storage best practices of 'Cripps Pink' and its clones. However, no amount of browning is acceptable, which increases the risk for claims. Browning is often also seasonal. And the poor understanding of seasonality creates a potential risk of long-term damage to this flagship cultivar, through reduced consumer trust.

Hence, a growing understanding of the relevant risks presents a significant mitigatory advantage, but only with ongoing research.

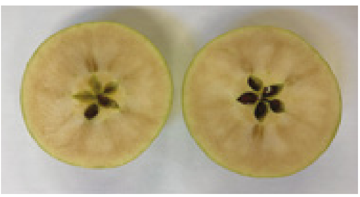
There are two types of IB – diffuse browning (DB) and radial browning (RB), with the former being historically more common in South Africa. Combination browning (CB) arises when both DB and RB are present in the same fruit. This dual presence makes it tricky to definitively identify related trends.



Diffuse browning (DB).



Radial browning (RB).



Combination browning (CB).

In 2026, the stakes are high, with Hortgro having projected a 5% increase in 'Cripps Pink'/Pink Lady® export volumes. Hortgro is the representative industry body for South African pome and stone fruit growers. Retention of marketable yield and brand reputation for this cultivar continue to hinge heavily on the effective management of IB. But devising a suited, robust risk mitigation strategy is dependent on on-going research.

Background

A targeted research project sought to explore unanswered questions regarding IB of 'Cripps Pink' apples. The project was co-funded by the Post-Harvest Innovation (PHI) Programme and Hortgro.

Dr Elke Crouch, Senior Lecturer in the Department of Horticultural Sciences at Stellenbosch University, led the research project. This article focuses on exploring the risks related to IB development.

"We cannot predict IB accurately yet, but we can highlight the risk factors," noted Dr Crouch. She was speaking from the premise of the multi-factorial predisposition of apple cultivars to IB, as well as its relativity to the applicable growing region.

An integrated approach is integral to the effective overall management of IB. Ongoing combined climate monitoring, canopy management, and maturity-specific storage practices stand to enhance post-harvest consistency, extend storage life and meet premium market standards for the South African apple industry.

Fruit- and orchard-specific factors like irrigation practices, possibly pre-harvest spray applications (for which there is currently limited research), maturity, fruit size, biological composition, current and previous season yield (crop load) and tree age must also be scrutinised ongoingly as contributing factors to IB development. Regarding orchard drivers for the different defects, these were the key qualitative ones: for RB – growing region, previous season and current season yield; CB and CO_2-induced defects (previous season yield, but unclear; current season yield CO_2 core browning, and core cavities more in low yield) – growing region, rootstock row orientation, tree vigour, and previous and current season yield; superficial scald – tree vigour; DB and peduncular scald – none identified. Collectively, these can provide critical guidance in determining the impact and relevance of these factors, and to create an orchard risk profile.

As for climatic factors, related variables and the accumulation of growing degree days (GDD) above 10°C from full bloom to harvest, are equally important considerations. GDD refers to the thermal time index that quantifies heat accumulation above a defined base temperature (in this case, 10°C).

Once there's a good understanding of the factors involved and the seasonal risk of IB development due to temperature, along with advanced post-harvest research and technologies, these can facilitate effective post-harvest management to reduce risk and optimise market planning strategies.

Table 1 provides a snapshot of relevant risks to consider.

And below is a comparison of pre- and post-harvest factors that influence cultivar-specific browning types. This comparative knowledge is instrumental in investigating relevant research gaps (Ramos, 2026).

Pre-harvest impact

This phase can be thought of as the genesis of IB risks – where it all begins.

The research team invested thousands of hours plotting, investigating and interrogating relevant aspects of the pre-harvest phase.

For storage facilities, becoming au fait with relevant pre-harvest risk factors and the apple profiles that they receive, will go a long way to equipping them to significantly reduce browning risk by adjusting their storage methods and time accordingly.

Orchard/quality factors

RB risk increased when previous and current yields exceeded 70–80 t/ha and fruit size was below 69 mm. Core browning (CB) was most prevalent in orchards with high tree row volumes (>2200 L) and large fruit (>140 g) with low sugar levels [Total Soluble Solids (TSS <14%)]. Similarly, superficial scald was highest in large fruit (>130 g) with low TSS. CO_2-induced disorders, including flesh browning and internal cavities, were strongly associated with seedling rootstocks, vigorous canopies, and advanced starch breakdown.

High yields (>79–82 t/ha) helped minimize CO_2 flesh browning and core cavities, and higher acidity [titratable acid (TA)] reduced browning risks.

Ripening rate

The highest DB incidence was associated with a faster rate in ground colour breakdown, increase in mass, faster starch breakdown, and a lower before-storage blush percentage and colour, and after-storage TA and firmness.

The highest RB incidence was associated with the slowest increase in circumference, mass, seed colour change and starch breakdown.

Temperature

Climatic factors

Thermal conditions during the growing and ripening phases dictate fruit stability in storage. RB incidence is lower in cooler overall seasons that have a warmer ripening period shortly before harvest. In contrast, DB is triggered by extreme temperature spikes and high maximum temperatures in the final month before harvest. These temperature surges appear to cause a faster starch breakdown and more mature fruit, reducing the fruit's tolerance to long-term cold storage.

However, DB risk is lower in longer growing seasons (≥188 days) with cooler ripening phases.

Whilst thermal effects on superficial scald are less clear, peduncular scald is reduced by cooler ripening phases, also likely influencing maturity. Finally, CO_2-induced disorders like core browning and core cavities are least likely after warmer cumulative growing seasons, whereas flesh cavities are exacerbated by low heat units [growing degree hours (GDH)] in the four weeks leading up to harvest. GDH measures heat accumulation to predict plant development stages.

Post-harvest impact

Long-term storage regimes

There are various long-term storage regimes available to effectively manage IB incidence.

Long-term storage technology

Dynamic Controlled Atmosphere Chlorophyll Fluorescence (DCA-CF) regulates oxygen at the lowest oxygen limit according to the fluorescence of the fruit, below 1 kPa, and reduces the risk of superficial scald development in 'Granny Smith'. Controlled atmosphere (CA) regulates oxygen at a constant oxygen level – in this trial, at 1,5 kPa.

Results showed that regardless of low oxygen storage techniques, maturity played a bigger role in long-term storage than the storage technique employed. Storing fruit with a high starch breakdown in low oxygen storage, for extended periods of time, will result in high IB.

Literature shows that in the case of RB, CO_2 levels >1 kPa in CA were found to increase susceptibility. 'Cripps Pink' and its strains are CO_2-sensitive above 1 kPa.

Long-term storage temperature

Similarly, the team was confronted with the dilemma of decreased DB incidence when storing fruit at 3 °C, but with compromised fruit quality. Low storage temperatures possibly result in a stress response in fruit, increasing reactive oxygen species (ROS). And this physiological post-harvest factor possibly overcomes the cell antioxidant function, giving rise to DB development. Research team member, Heleen Tayler, has proven that step-down cooling from 3 °C works well in inhibiting disorder development and is captured in three storage regimes in the industry best practice guidelines.

For RB, an incidence decrease was also observed in these same trials when step-down cooling was applied from 3 °C to 1 °C. Therefore, the research team advises following the best practice guidelines closely to minimise overall IB incidence.

1-Methylcyclopropene and Diphenylamine

Lower DB incidence was recorded in 1-Methylcyclopropene (1-MCP)-treated fruit (Butler, 2015; Crouch et al., 2015; de Jong, 2023; James, 2007; Majoni et al., 2013). And this category of fruit also exhibited lower scald and overall IB incidence (Majoni et al., 2013; Store-it Group, 2022). 1-MCP inhibits gaseous ethylene, thereby retarding ripening and extending shelf life.

Regarding CO_2-related browning, the application of Diphenylamine (DPA) – a post-harvest chemical antioxidant – is reported to decrease the incidence of superficial scald and IB by retaining ascorbic acid levels and decreasing H_2O_2 production. Unfortunately, DPA is not allowed in many of our major markets, including the European Union (EU) and the United Kingdom (UK).

Harvesting

Harvesting inner and outer canopy fruit together and disregarding their distinct difference in maturity poses a significant risk of IB development when these fruit are stored together.

Other important considerations for risk avoidance include harvesting at optimum maturity and placing fruit in cold storage, soonest after harvesting, to reduce maturity progression before storage.

Unrefrigerated transport over long distances, after harvesting in hot conditions, causes starch breakdown to reach post-optimum levels, even though fruit were harvested at optimum starch breakdown. This results in high IB during low oxygen long-term storage.

Mineral composition

A previous study by Butler, in the same group, found insufficient potassium (K) and low K to magnesium (Mg) in fruit that were prone to IB development. Fruit low in K content is more susceptible to low temperature breakdown (Bramlage, 1993) and cold injury is one of the leading causes of DB (Bramlage et al. 1980; James et al. 2005).

Resistance towards chilling injury in fruit high in K is associated with an increase in phospholipids, membrane permeability and improvement of the biochemical and biophysical properties of cells (Hakerlerker et al., 1997). K increases resistance towards chilling temperatures by regulating osmotic and

Table 1: A snapshot of the most pertinent risks to consider regarding IB

Risk factors	Diffuse browning (DB)	Radial browning (RB)	Combination browning (CB)
Maturity	Post-optimum fruit.	Immaturity and post-optimum fruit.	Over-maturity.
Pre-harvest temperature (0-40 days before harvest)	Warmer temperatures during the ripening phase (>255 GDD).	Cooler temperatures during the ripening phase (<265 GDD).	Depends on DB and RB interactions.
Growing region (though factors like harvest maturity and cooling rate play a much bigger role)	Not applicable.	✓	✓
Growing season temperature (0-22 WAFB)	Not applicable.	Warmer growing season (> 34216 GDH). Warmer during and after cell enlargement phases. Significant for 0-2, (cell division), 8-10, 14-16, 18-20 (cell enlargement) weeks after full bloom (WAFB).	Depends on DB and RB interactions.
Growing season length (d)	≤182 days.	Not applicable.	Not applicable.
Fruit size	Large (>70 mm). Mass differences not significant.	Small (<69 mm). Mass differences not significant	Large (>69 mm) (>140 g).
Storage	• >3 months in CA storage • chilling injury at -0.5 °C • rapid cooling • extended cold storage • step-down cooling reduces risk.	• long-term CA • high CO_2 levels • step-down cooling reduces risk.	• >3months in CA storage -0.5 °C • step-down cooling reduces risk.
Canopy position (currently, there is limited research)	Not applicable.	Inner (if harvested at optimum).	Not applicable.
Blush	Lower blush percentage (<35%) and intensity (1.8).	Inside canopy; lower blush fruit (canopy trial).	Not applicable.
TA	Lower TA (0.3% - after storage).	Higher TA (0.7% before storage).	Lower TA (0.4% - after storage)
TSS	Not significant	Not applicable.	Lower TSS (<14% - after storage).
Seed Colour Index	Not significant	Lower seed colour index (5.2).	Not significant
Tree vigour/ row volume (L/ha)	Not applicable.	Not applicable.	Vigorous >2200 L/ha.
Yield (t/ha) Previous season Current season	Not applicable.	Higher previous (>68 t/ha) and current season yield >80 t/ha.	Not applicable.
Starch breakdown	Neglecting to measure starch breakdown in apples from the inside of the canopy enhances the risk of exceedance in starch breakdown. Starch breakdown as maturity parameter, gives an indication of suitability for long-term low oxygen storage.		
Harvesting (non-selective)	✓	✓	✓
Neglecting step-down cooling	✓	✓	✓
Extended transport time	✓	✓	✓
Knowledge gaps	✓	✓	✓

A Pink Lady® Orchard.

water potential of cell sap and reducing electrolyte leakage (Singer et al. 1996). However, more research is required to establish a definitive link over multiple seasons.

Knowledge gaps

Failing to close knowledge gaps was flagged by researchers as a significant potential risk to effective IB management.

Future recommendations/next steps

To fully maximise current research outputs and findings, the research team recommends developing a multi-factor storability index (MFSI) for browning risk assessment, with the goal of:

- Identifying specific biomarkers, like ascorbic acid depletion rates or ethylene precursors that link pre-harvest climatic factors (e.g. temperature) to the advancement of physiological disorders, like IB and superficial scald.
- Developing a decision tree model that prioritises and integrates parameters that include ripening rate, tree row volume, and minimum night temperatures. This is to provide a real-time storability risk score for growers and to facilitate research-based decision-making. It needs to be done within regions, or with two contrasting regions to limit variation. Currently cumulative risk factors should be considered on an orchard level. Parameter thresholds should also be validated.
- Single factors identified within this multifactorial experiment should be tested in separate trials. Single-factor contrasts are required to confirm the effect of certain risk factors associated with IB types, as IB is influenced by many factors at the same time (also in this trial). These further studies will confirm whether the tested variable does in fact play a significant role, when all other factors are held constant.

"Cripps Pink" apples.

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