

Horticulture Innovation Australia

Final Report

Improving consumer appeal of Honey Gold mango by reducing under skin browning and red lenticel discolouration

Peter Hofman
The Department of Agriculture and Fisheries (DAF)

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Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

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Summary

'Honey Gold' is a relatively new Australian mango variety that is gaining in popularity among consumers. The fruit are, however, susceptible to developing under-skin browning (USB) and red lenticel spots. These superficial quality defects result in downgrading of fruit consignments and financial loss.

USB can develop in response to a combination of physical (e.g. abrasion) stress and low (e.g. <14°C) temperature exposure during postharvest handling. Fruit produced in hot tropical environments, such as the Northern Territory, are particularly susceptible for reasons that are unresolved. Development of red halos around lenticels is often associated with heavy rainfall prior to harvest. Entry of rain water into lenticels is proposed to trigger a wound response leading to localised red pigment production.

The current project aimed to improve the consumer appeal and profitability of 'Honey Gold' mango by:

- Reducing the occurrence of USB by exploring the influence of pre-harvest and harvest practices.
- Identifying strategies to minimise red lenticels using inhibitors and promoters of red skin colour.

Harvesting 'Honey Gold' mangoes from the Northern Territory at night was the most effective practice for reducing the sensitivity of fruit to developing USB. Fruit harvested between 10 PM and 10 AM displayed 50-75% reductions in USB incidence compared to those picked at 2 PM. The higher level of USB in the afternoon harvest was related to relative sap phytotoxicity. These findings prompted 'Honey Gold' growers in the Northern Territory to harvest fruit at night. Piñata Farms, who market 'Honey Gold', reported that since adopting night harvesting in 2014/15, USB has decreased from 20% of the Northern Territory crop to <1% in 2016/17. Also, harvesting at night facilitated a 20% increase in picking speed.

Pre-harvest bagging of fruit was the most reliable technique for reducing red lenticels. Applying brown paper or Tyvek® plastic bags at 4 weeks before harvest reduced this skin defect by 67-85% relative to non-bagged fruit. The bags blocked up to 90% of sunlight and, in turn, reduced red pigment production, including skin blush. In contrast, postharvest exposure of fruit to blue LED light for 3-4 weeks at 22°C enhanced skin blush. By increasing blush, this treatment suggests the potential to mask red lenticels.

The current project also aimed to verify and optimise 'Honey Gold' crop forecasting and downgrade analysis procedures developed in a previous project, MG10009. Accumulation of ≥ 1500 heat sums above a 12°C base from full flowering was confirmed to predict the earliest harvest date to provide fruit with good eating quality. In-market fruit quality downgrade analysis with improved recording and report back systems was well received by growers. The feedback stimulated practice change that translated into increased fruit yield and quality. Formal downgrade analysis at pack sheds is also recommended.

For fruit that were downgraded, alternative products and markets were identified to improve returns. A non-premium fruit line was developed and marketed successfully. Juice grade fruit were trialled as a new ingredient in an existing mango ice block product. Two major retailers relaxed grading standards and rationalised fruit size by state markets to accept premium fruit with minor defects, and of all sizes.

Implementation of these key project outcomes has contributed to significantly improving the commercial viability of 'Honey Gold' mango production, particularly in the Northern Territory.

Keywords

Crop forecasting; downgrade analysis; 'Honey Gold'; mango; night harvesting; non-premium products; red lenticel; under-skin browning.

Introduction

'Honey Gold' is an Australian mango cultivar with attractive fruit colour, fibre-free flesh and a pleasant flavour (Sammon and Macleod, 1999). It was commercialised by Piñata Farms Pty Ltd in 2009 and now accounts for 10% of Australian mango production (G. Scurr, pers. comm., 2016). Two prior HAL projects, MG06022 and MG10009, helped to improve 'Honey Gold' production efficiency and fruit quality.

'Honey Gold' fruit can develop unsightly under-skin browning (USB). Symptoms are grey-brown bruise-like lesions beneath the skin surface (Hofman et al., 2010). This defect develops after harvest, typically as fruit arrive at markets. Affected fruit need to be removed from consignments, resulting in financial loss. Observations from projects MG06022 and MG10009 indicated that USB develops in response to physical (e.g. vibration) stress during handling and transport in association with exposure of fruit to low (e.g. <14°C) temperature (Marques et al., 2012). Pre-harvest variables and harvest practices may also influence the occurrence of USB. For example, the incidence of USB is higher in fruit produced in hot tropical regions relative to cool sub-tropical environments (Hofman et al., 2010). Preliminary findings from project MG10009 also suggest that USB might be reduced by harvesting fruit at night.

'Honey Gold' mango can also develop red halos around lenticels on the fruit surface when grown in cooler, wetter sub-tropical districts. Such red discolouration has been associated with insect infestation, chilling injury and ethylene exposure (Pesis et al., 2000; Winston et al., 2014). Wound response mechanisms are generically known to involve ethylene and other biochemical signals, such as methyl jasmonate. Ethylene synthesis inhibitors (e.g. Retain™) and ethylene sources (e.g. Ethrel®) are used, for example, to slow apple fruit ripening and to induce pineapple flowering, respectively. Such biochemical tools potentially could be applied to help understand the regulation of red lenticels in mango and to inform potential management strategies.

Crop forecasting is an essential tool to help balance fruit supply with customer demand and reduce the risk of oversupply during critical periods. A crop forecasting model was developed and implemented in project MG10009. Further data was needed to fine tune the model.

Project MG10009 also developed methodology for fruit quality downgrade analysis and provided training for 'Honey Gold' packhouse operators. However, a more efficient recording, summary and report back system was required.

Premium grade 'Honey Gold' mango fruit that are free of defects often command about 20% higher returns than do first grade fruit (G. Scurr, pers. comm., 2014). Given that premium fruit can account for just 10-50% of total packout, development of alternative products and lucrative outlets for non-premium fruit was required to increase net returns.

The purpose of this follow-on project was to improve the consumer appeal of 'Honey Gold' mango by:

- Reducing the commercial occurrence of USB by verifying the diurnal time of harvest effect and testing the efficacy of soft tray inserts and chemical treatments.

- Identifying management strategies to reduce the red lenticel disorder by undertaking laboratory- and field-based trials with both inhibitors and elicitors of red skin colour development.
- Verifying the accuracy of a crop forecasting model through collection of additional datasets.
- Improving fruit quality by encouraging adoption of an optimised downgrade analysis system.
- Identifying alternative processed products and markets for non-premium 'Honey Gold' fruit.

Methodology

Activity 1: Reducing USB

Projects MG06022 and MG10009 established that pre- and postharvest factors contribute to USB development in 'Honey Gold' mango (Winston et al., 2010, 2014). However, considerable farm-to-farm and seasonal variation in USB occurrence exists. In the current activity, meta-analysis of data from 40 experiments on USB from 2011/12 to 2014/15 using fruit from seven farms was completed to identify overarching patterns and relationships. A review of current knowledge and promising leads from projects MG06022 and MG10009 was also completed with project partners. Together, the analysis and review were used to prioritise the following list of best bets for strategies to reduce USB:

Irrigation: Fruit typically take up water and swell at night and lose water to the strong leaf transpiration stream during the day. Night-harvested fruit are evidently relatively less susceptible to USB. Hence, increased irrigation potentially may increase overall fruit water status and reduce USB susceptibility.

Nutrition: Fruit mineral composition, particularly cations such as calcium, is often associated with fruit physiological disorders associated with cell and tissue breakdown. Improving fruit calcium nutrition could potentially reduce USB incidence.

Rootstock and soil type: Prior experiments consistently showed significant differences in USB susceptibility for fruit from two different farms in the Katherine region. These farms differed in soil type and rootstock, suggesting that these factors may be involved in USB susceptibility.

Chemicals: Photon® SG is marketed for reducing the impact of environmental stress (e.g. light, heat) in fruit crops and may influence sensitivity to developing USB. Natural compounds such as methyl jasmonate, oxalic acid and salicylic acid have been reported to prevent chilling injury in mango fruit (Gonzalez-Aguilar et al., 2001; Ding et al., 2007; Li et al., 2014) and may also reduce USB.

Varieties: While the sensitivity of 'Honey Gold' fruit to developing USB has been documented, the relative susceptibility of other mango varieties has not been determined.

Diurnal harvest time: Preliminary data from project MG10009 suggested that fruit harvested at night were less sensitive to developing USB.

Tray inserts: USB is often associated with physical damage to the fruit skin after harvest. Damage to the skin through vibration during road-freight was identified in project MG10009 as a major contributing factor. Softer tray inserts may reduce the severity of USB.

Experiments were then designed to evaluate the impact of differences in pre-harvest, harvest and postharvest practices on USB. The experiments were completed at farms in the Katherine region of the Northern Territory which had a history of producing fruit with high susceptibility to USB. Fruit were harvested at commercial maturity. They were lightly abraded with sandpaper and held at 13°C for 6 days to simulate transport-related vibration (Winston et al., 2014). Fruit were assessed for USB at ripe.

The following experiments were undertaken:

Irrigation: In the 2014/15 and 2015/16 seasons, irrigation durations (1, 2 hours), frequencies (twice, three times daily, once every 2 days) and timings (decrease or increase prior to harvest) were compared.

Nutrition: In 2014/15 and 2015/16, additional phosphorus (super phosphate, which contains extra calcium) was applied for comparison to trees just before flowering. On an adjacent block, double the commercial rate of Biogyp (a liquid formulation of gypsum / calcium) was applied for comparison during early stages of flowering and fruit growth.

Rootstock and soil type: In 2014/15, fruit for comparison were harvested from trees established on seedling 'Kensington Pride' rootstocks that were growing on either a light sandy loam or a silty loam.

Chemicals: Photon® was applied to 'Honey Gold' trees by repeated foliar sprays throughout the 2015/16 growing season, with and without Screen™ (a reflective coating), and by fertigation.

In 2015/16 and 2016/17, the efficacy of postharvest vapour or dip treatments with methyl jasmonate, salicylic acid and oxalic acid to potentially reduce USB was evaluated.

Varieties: In 2015/16, the relative susceptibility to USB of major Australian mango cultivars 'Kensington Pride', 'R2E2', 'Calypso', 'Honey Gold' and 'Lady Jane' was assessed.

Diurnal harvest time: In the 2013/14 and 2014/15 seasons, 'Honey Gold' fruit were harvested at 4-hour intervals during a 24 hour diurnal cycle. Additional fruit were harvested from a second farm at 7:30 AM and 4:30 PM. Sap was collected from each fruit at harvest for compositional analysis by gas chromatography mass spectrometry (GCMS). Additional fruit not subjected to the abovementioned abrasion test were road-freighted in commercial trailers at 16°C from Katherine to south-east Queensland in 4 days for evaluation of USB incidence.

Tray inserts: In 2013/14 and 2014/15, a soft shallow expanded polystyrene tray insert was compared against the standard industry plastic insert in order to reduce vibration damage. Transport was simulated by placing the fruit in trays onto a vibration table delivering 15 Hz for 3 or 9 hours at 12°C or 20°C. Fruit were later assessed for physical damage and USB.

These experiments were expanded in 2015/16 to include evaluation of five types of insert: viz. paper, shallow foam, deep foam, plastic standard and inverted plastic. Additional experiments on the vibration table explored the use of foam pads within stacks of trays to dampen vibration.

In 2016/17, the most promising tray inserts were tested during road-freight in refrigerated trailers from Katherine to south-east Queensland. Data loggers secured to trailers recorded vibration during transit. A separate load of fruit was also sent to Melbourne for laboratory-based vibration simulation.

Activity 2: Reducing red lenticels

The development of red lenticels is often associated with heavy rainfall in the weeks leading up to harvest. Infiltration of rain water into the lenticel cavity possibly induces a stress response involving the production of red anthocyanins, the same pigment associated with skin blush. We hypothesised that the visual impact of this disorder might be lessened by: preventing water from entering lenticels, reducing the stress response, or enhancing blush to mask red lenticel development.

As a first step, a review of literature was completed to identify strategies for minimising red lenticels. A series of field and laboratory experiments were then designed. The experiments were undertaken at orchards near Wamuran in south-east Queensland (2014/15) and Yelgun in northern New South Wales (2015/16, 2016/17) that had a history of red lenticel damage on fruit.

In 2014/15, fruit were dip-treated with a carnauba wax or RainGard[®], a protective film, to minimise rain contact. Additional fruit were sprayed with the anti-ethylene compound, aminoethoxyvinylglycine provided as ReTain[®], or covered with white paper bags with a view to reduce blush. Sucrose, fructose and the ethylene-releasing agent Ethrel[®] were sprayed onto other fruit in an attempt to increase red blush. All treatments were applied at 4 weeks before harvest. Dips and sprays were re-applied every 5-7 days. Additional non-treated fruit were gas-treated after harvest with various ethylene concentrations. Fruit were assessed for skin colour, firmness, blush and red lenticel disorder at harvest and when ripe.

In 2015/16, pre-harvest bagging was explored further using clear, blue and red plastic bags and brown paper bags to manipulate the light wavelengths reaching the fruit. The effects of light on blush development was also evaluated through postharvest exposure to far-red, red, blue, white and ultra-violet wavelengths of light emitted from LED or fluorescent lamps. A variety of inducers (viz. methyl jasmonate, salicylic acid, oxalic acid), ethylene inhibitors (viz. ReTain[®]) and promoters (viz. Ethrel[®]) were also applied as pre- and postharvest treatments to test for their potential effects on blush.

In 2016/17, promising pre-harvest bagging and postharvest blue LED light exposure treatments were further tested. The tests included bagging with spun-bonded plastics (viz. frost cloth and Tyvek[®]) and exposure to different blue LED lights at two holding temperatures.

Pre-season planning and post-season review meetings were consistently held with Piñata Farms and collaborating growers.

Activity 3: Improving crop forecasting

The objective of this activity was to collect ongoing data to confirm the accuracy of a 'Honey Gold' crop forecasting model developed in project MG10009. This predictive model was based on earlier observations that the accumulation of 1,500 heat units as degree days above 12°C from a standard flowering stage was generally required for fruit to reach an optimal harvest maturity.

Data loggers that recorded air temperature were installed at 10 'Honey Gold' orchards in the Northern Territory and Queensland. The dates when $\geq 50\%$ of the panicles on $\geq 50\%$ of the trees reached full bloom (i.e. stage i) were recorded by collaborating growers. Full bloom was selected as the starting point for heat sum accumulation rather than earlier flowering stages, as previously recommended for hotter production environments in the Northern Territory. Daily heat sums were then determined. The estimated date of fruit maturity was calculated in a Microsoft[®] Excel[™] spreadsheet by adding the daily heat units until the required heat sum was reached. The model was validated by harvesting random fruit at different times leading up to the predicted harvest date and assessing the fruit dry matter content.

Findings were shared with Piñata Farms and collaborating growers leading up to harvest and at annual meetings.

Activity 4: Optimising downgrades analysis

Fruit that are downgraded due to quality defects represent a loss of potential revenue. Project MG10009 developed a downgrades analysis protocol to help 'Honey Gold' packers and wholesalers document and

diagnose causes of fruit quality loss. However, a number of businesses had not adopted this system, citing issues with data entry and reporting. The purpose of the current activity was to optimise the analysis process and demonstrate its benefits to 'Honey Gold' growers and supply chain partners.

As an initial step, the Honey Gold coordinator at Piñata Farms visited all farms to discuss the downgrade analysis system. Pack shed operators were encouraged to assess non-premium and reject fruit at least twice daily and record reasons why they were downgraded. Growers were supplied with the QDAF Mango Quality Assessment Manual (Holmes et. al., 2010), which has photographs showing fruit quality defects. Piñata Farms provided training in 'Honey Gold' ripening and fruit grading to staff at LaManna, who ripened growers' fruit in Sydney, Melbourne and Adelaide. LaManna used the Muddy Boots® software to generate quality reports for growers. The reports described the quality of ripened fruit and reasons for any downgrade.

Piñata Farms, Tropical Horticultural Consulting and QDAF worked with growers to review the downgrade analysis and identify areas for improved practice.

Activity 5: Identifying non-premium fruit products

The overall objective of this activity was to increase the return for non-premium 'Honey Gold' mango fruit that were downgraded due to issues with size and skin quality. Second grade fruit are often used for juice processing. However, demand for juice varies between seasons and returns are low. Meetings within Piñata Farms were held to brainstorm and decide on which new markets, customers and products should be tested. These discussions highlighted opportunities to utilise non-premium fruit for other processed products and/or for fresh product categories that tolerate some cosmetic defects.

A manufacturer of mango ice blocks in Queensland, was approached by Piñata Farms to trial the inclusion of non-premium 'Honey Gold' fruit in their frozen product. Discussions were also held with Woolworths Ltd and Harris Farm Markets Pty Ltd to gauge their interest in trialling non-premium fruit in their newly created The Odd Bunch® and Imperfect Picks™ lines, respectively. In separate discussions, Woolworths and Coles Supermarkets Australia Pty Ltd were asked to consider relaxing their premium fruit quality specifications to include minor skin defects. Woolworths and Coles also agreed to trial selling a reduced range of 'Honey Gold' fruit sizes in different states.

At the end of each season, the project team evaluated the commercial viability of each strategy.

Outputs

Activity 1: Reducing USB

- Recommendations to avoid harvesting fruit during the afternoon to reduce USB to commercially insignificant levels. These recommendations are based on intensive diurnal harvest experiments completed in the Northern Territory and meta-analysis of data collected from 40 experiments across four seasons (2011/12 to 2014/15) and seven farms.
- Practice change by all 'Honey Gold' growers in the Northern Territory to harvest most fruit at night and introduce harvest aids with conveyor belts to reduce fruit injury. Since commencing night harvesting in 2014/15, the proportion of the Northern Territory crop with USB has decreased from 20% to >1%.
- Recommendations on more frequent irrigation regimes to increase fruit size, total yield and proportion of premium grade fruit and decrease the number of misshapen sunburnt fruit.
- Recommendations on the relative sensitivity of major Australian mango varieties to developing USB. 'Honey Gold' and 'Lady Jane' were the most sensitive, while 'Kensington Pride' and 'Calypso™' were the least susceptible. 'R2E2' fruit were moderately sensitive.
- An interview with Fresh Plaza was published online on 12 May 2014 in which Gavin Scurr, Managing Director of Piñata Farms, described the introduction of night harvesting at 'Honey Gold' farms in the Northern Territory. Fresh Plaza is the 'number one' online portal for the fresh produce industry, with more than 100,000 subscribers worldwide. It provides latest news, job advertisements and prices. (<http://www.freshplaza.com/article/132248/Harvesting-aids-a-boon-for-Honey-Gold-mangoes>).
- An oral paper presentation to the 20th International Horticultural Congress in Brisbane, Queensland on 21 August 2014 by Roberto Marques entitled *Evaluation of temperature management and packaging options to reduce under-skin browning in 'Honey Gold' mango fruit*. The presentation reported on research progress into management strategies to reduce USB and was attended by about 40 Australian and international horticultural scientists.
- An oral paper presentation to the 10th Australian Mango Industry Conference in Darwin, Northern Territory on 28 May 2015 by Peter Hofman entitled *Winning the battle against under-skin browning*. The presentation provided a summary of research progress into reducing USB and was attended by about 100 Australian mango growers and research and extension specialists.
- An article entitled *Researchers Discover Key to Reducing Skin Damage to Honey Gold* contributed by Peter Hofman was published in the July 2015 issue of Mango Matters on pages 18-19. The article summarised the research into diurnal harvest effects and recommendations for reducing USB. Mango Matters is a trade journal that is distributed by the Australia Mango Industry Association to growers and supply chain operators.

- A poster paper presentation to the XI International Mango Symposium in Darwin, Northern Territory on 29 September 2015 by Ahn Tram San entitled *Anatomy of skin disorders afflicting Australian mangoes*. The presentation provided a summary of research into understanding factors regulating lenticel discoloration and USB and was attended by about 100 mango research and extension specialists and several international mango growers.
- An oral paper presentation to the XI International Mango Symposium in Darwin, Northern Territory on 30 September 2015 by Peter Hofman entitled *Production and postharvest practices to reduce under-skin browning on 'Honey Gold' mango*. The presentation provided a summary of research progress into reducing USB and was attended by about 50 mango research and extension specialists and several international mango growers.
- PhD thesis by Guoqin Li entitled *Lenticel discoloration on 'B74' mango fruit and under-skin browning on 'Honey Gold' mango fruit* accepted by The University of Queensland on 8 December, 2015. This thesis reported on the initial research into the effects of diurnal harvest time, including the influence of fruit sap, and transport vibration on USB.
- An oral paper presentation to the International Symposia on Tropical and Temperate Horticulture in Cairns, Queensland on 23 November 2016 by Andrew Macnish entitled *Early morning harvesting reduces under-skin browning in 'Honey Gold' mango fruit*. The presentation provided an overview on research progress into reducing USB and was attended by about 60 tropical horticulture research and extension specialists and several Australian mango growers.
- PhD thesis by Anh Tram San entitled *Lenticel discoloration, under-skin browning and resin canal disorder in Australian mango fruit cultivars* accepted by The University of Queensland on 11 May, 2017. This thesis reported on the research behind the important discovery that the higher incidence of USB in fruit harvested during the afternoon was related to an increase fruit sap phytotoxicity.

Activity 2: Reducing red lenticel

- Preliminary recommendations on the use of pre-harvest bagging of 'Honey Gold' fruit to block light interception and red lenticel development.
- Preliminary recommendations on the potential benefits of postharvest exposure of 'Honey Gold' fruit to blue LED lights to enhance skin blush.
- A literature review report entitled *Literature Review: Red lenticel spotting and skin colour manipulation in mango* by Dion Harrison, Daryl Joyce and Peter Hofman in January 2015. This report describes known pre- and postharvest factors that regulate fruit colour and identified potential strategies to minimise the red lenticel disorder in 'Honey Gold' mango.
- An oral paper presentation to the 20th International Horticultural Congress in Brisbane, Queensland on 22 August 2014 by Shifeng Cao entitled *Postharvest light treatments increase skin blush in mango fruit*. The presentation reported on initial research into light treatments to increase fruit blush and was attended by about 40 Australian and international horticultural scientists.
- An oral paper presentation to the 20th International Horticultural Congress in Brisbane, Queensland on 22 August 2014 by Xi Yu entitled *3D modelling of mango fruit skin blush in the tree canopy*. The presentation reported on research into mapping the occurrence of fruit skin blush within the mango tree canopy and was attended by about 40 Australian and international horticultural scientists.

- An oral paper presentation to the International Symposia on Tropical and Temperate Horticulture in Cairns, Queensland on 23 November 2016 by Amrit Poudel entitled *Reddening disorder of 'Honey Gold' mango fruit and pre-harvest bagging and postharvest lighting*. The presentation provided an update on research progress into managing red lenticel damage and was attended by about 60 tropical horticulture research and extension specialists and several Australian mango growers.

Activity 3: Crop forecasting

- An oral presentation to the Honey Gold Congress in Melbourne, Victoria on 6 May 2015 by Ted Winston. The presentation provided an update on forecasting data collected during the 2014/15 mango season and was attended by about 40 'Honey Gold' mango growers and chain businesses.
- An article entitled *Crop Forecasting to Predict the Start of Harvest for 'Honey Gold' Mangoes* contributed by Ted Winston, Peter Hofman and Gavin Scurr is currently *in press* for an upcoming issue of Mango Matters. The article summarised the general progress and benefits of the crop forecasting program. Mango Matters is a trade journal that is distributed by the Australia Mango Industry Association to mango growers and supply chain operators.
- An oral presentation to the Honey Gold Congress at Airlie Beach, Queensland on 1 May 2017 by Ted Winston. The presentation provided an overview of crop forecasting model reliability during the 3-year project and was attended by about 40 'Honey Gold' mango growers and chain businesses.
- A final project report confirming that the forecasting model using 1,500 heat units was accurate.

Activity 4: Downgrade analysis

- An article entitled *Using downgrades analysis to increase the percent packout of premium grade 'Honey Gold' fruit* contributed by Peter Hofman, Ted Winston and Gavin Scurr is currently *in press* for an upcoming issue of Mango Matters. The article summarised the progress and benefits of the downgrade analysis program.
- Demonstration of Muddy Boots® software to generate concise and easy to interpret fruit quality downgrade reports. Muddy Boots® used a colour system (e.g. green = good, amber = minor defects, red = major defects) to report on the quality of fruit after ripening in central markets.
- A final project report confirming that in-market downgrade analysis with improved data recording and reporting contributed to improved practice and fruit quality outcomes.

Activity 5: Non-premium fruit products

- Commercial viability studies (commercial in confidence)
- Inclusion of non-premium 'Honey Gold' fruit in proprietary frozen mango ice blocks.
- Development and commercialisation of 'Honey Gold Odd Bunch' and 'Honey Gold Imperfect Picks' non-premium fruit product lines at Woolworths and Harris Farm Markets, respectively.
- Acceptance by retailers Coles and Woolworths to relax premium fruit quality specifications to include minor skin defects.
- Acceptance by retailers Coles and Woolworths to rationalise fruit sizes marketed to different states.

Outcomes

Activity 1: Reducing USB

'Honey Gold' fruit harvested at night and early morning (i.e. 2200 to 1000 hours) developed 2- to 4-fold less USB after a standard abrasion test than did fruit picked at 1400 hours. This finding was consistent across two seasons and two farms and confirms preliminary data from project MG10009. Meta-analysis of data collected from 40 experiments over four seasons further highlighted a distinct peak in USB for fruit harvested from 1200 to 1400 hours. Higher temperature, lower relative humidity and higher vapour pressure deficit at harvest were associated with increased incidence of USB. As a consequence, it is now standard practice for all 'Honey Gold' growers in the Northern Territory to harvest at night. Piñata Farms reported that since adopting night harvesting USB has decreased from 20% of the Northern Territory crop in 2013/14 to <1% in 2016/17. Harvesting at night in cooler temperatures has also been associated with a 20% increase in picking speed.

The higher USB incidence in the afternoon harvest was related to sap phytotoxicity. An increase in the concentration of key aroma volatile compounds 2-carene, 3-carene, α -terpinene, p -cymene, limonene and α -terpinolene in the sap of fruit picked at 1400 hours contributed to this phytotoxicity. Sub-epidermal browning similar to USB could be induced by injecting spurt sap from the afternoon harvest under the skin, but very little browning occurred following injection of spurt sap from the morning harvest. Anatomically, USB was characterised by dark-brown sub-epidermal cells surrounding resin ducts. It was also associated with starch retention and phenolic deposition in the cells next to resin ducts.

'Lady Jane' mangoes produced near Katherine in the Northern Territory exhibited a similarly high sensitivity to USB as 'Honey Gold'. 'R2E2' fruit were moderately susceptible, while 'Kensington Pride' and 'Calypso™' mangoes were largely resistant to USB. The results confirm commercial observations that 'Honey Gold' fruit produced in the Northern Territory are particularly prone to developing USB.

In simulated transport experiments, 'Honey Gold' fruit packed tightly into paper tray inserts showed less physical damage than those in standard plastic inserts or deep profile soft foam liners. Fruit in inverted suspension style inserts or shallow foam liners with limited support showed the most damage. Relative to the standard plastic insert, the different test inserts did not reduce USB during a road-freight experiment. However, fruit transported in truck trailers with leaf spring suspension developed more USB than did those transported on air ride suspension. Insertion of foam layers within the pallet stack did not reduce fruit damage and in some cases increased vibration and USB on fruit in the uppermost trays.

There was no consistent effect of irrigation, phosphorus and calcium nutrition, rootstock or soil type on the susceptibility of fruit to developing USB.

Pre-harvest sprays of fruit with Photon® and postharvest treatment with methyl jasmonate, salicylic acid and oxalic acid also did not consistently reduce USB.

Increasing the irrigation frequency from the standard of once every 2 days to two or three times daily increased yield by 16-33% through greater retention of fruit on trees and increased fruit weight. Daily

irrigation reduced fruit dry matter by 1-2% at commercial harvest relative to standard irrigation. It also reduced the number of count 14-18 fruit and increased count 10-12 fruit. In addition, daily irrigation reduced the incidence of deformed / sunburnt fruit and increased the packout of premium fruit.

Activity 2: Reducing red lenticels

Pre-harvest bagging of 'Honey Gold' fruit was the most consistent technique for reducing red lenticel damage. Covering individual fruit 4 weeks before harvest with bags made from either white or brown paper or Tyvek® spun-bonded plastic reduced the incidence and severity of red lenticel damage by 3- to 6-fold relative to non-bagged fruit. Brown paper and Tyvek® bags blocked up to 90% of sunlight reaching the fruit surface and this translated into reduced development of fruit blush area and red-purple colour intensity. Pre-harvest bagging effects were reproduced across three seasons.

Postharvest exposure of 'Honey Gold' fruit to blue LED lights for 3-4 weeks at 22°C enhanced the development of blush area and colour intensity as compared to fruit stored in the dark. Blush development was greater in fruit treated at 12°C than 22°C. This treatment response highlights the potential to mask red lenticel expression. However, further research is required to reduce the exposure time and increase the blush response. Ripening fruit with high concentrations of ethylene (viz. 20-500 parts per million) also slightly increased red lenticel severity and the red colour of blushed areas relative to non-treated controls. Treatment with anti-ethylene agents (e.g. ReTain®) did not reduce red lenticel and fruit blush.

An attempt to prevent water entry into lenticels via pre-harvest treatment of fruit with RainGard® and carnauba wax showed promise by reducing red lenticel damage by about 30-50% relative to controls. There was no consistent effect of other treatments (viz. sucrose, fructose and Ethrel® sprays, far-red, red, white and ultra violet light) on red lenticel damage.

Activity 3: Improving crop forecasting

The current project confirmed that 1500 accumulated heat sums above 12°C from full flowering was a reliable indicator for predicting the earliest harvest date for 'Honey Gold' fruit. This initial harvest date closely corresponded to fruit developing 15% dry matter. These data were verified across three seasons, and confirm preliminary data from project MG10009 and, thereby, the reliability of the crop forecasting model parameters. The current work also refines and extends the original model recommendations by Diczbališ et al. (1999) for 'Kensington Pride' produced under Northern Territory conditions to 'Honey Gold' cultivated in both the Northern Territory and Queensland. Survey data gathered during the project showed that growers in Katherine and the Burdekin generally commenced harvesting 'Honey Gold' mangoes just after fruit had accumulated 1500 heat units. In other production districts, harvesting started at slightly higher (e.g. 1600-1900) heat sums, which was largely due to overlapping picking schedules with other mango varieties. Fruit assessments indicated that 15% dry matter was the minimum required for 'Honey Gold' fruit to develop full flavour when ripe. The Australian Mango Industry Association recently adopted 15% dry matter as the maturity standard for 'Honey Gold'.

Activity 4: Downgrade analysis

Piñata Farms reported that there was a significant improvement in 'Honey Gold' fruit quality from most farms over the past 3 years. This could be attributed to the training provided and awareness gained from each consecutive year of conducting downgrade analyses. The improvement was observed throughout the supply chain from tree hygiene and shed management practices through to the ripening

process. Taken collectively, this translated into increased grower profitability from better understanding of the causes of downgrades and their implementation of targeted control measures to reduce quality issues. Some 'Honey Gold' growers were reluctant to complete formal downgrade analysis at the packing shed, and relied on general observations. When the analysis was completed down the chain by a ripener, the feedback was well received and stimulated changes in practice to correct any perceived quality defects. Muddy Boots® software was trialled as an alternative to Microsoft® Excel™ for fruit downgrade analysis by the ripener, LaManna. It provided user-friendly options for data entry and reporting.

Activity 5: Non-premium fruit products

'Honey Gold' juice grade fruit were successfully included as a key ingredient in proprietary frozen mango ice blocks. The flavour that it contributes to the product prompted positive feedback from consumers. Supplying fruit for ice blocks increased returns to Piñata Farms for their juice grade fruit, particularly in seasons where juice contracts were rationed or not available. Basic benefit-cost analysis showed that this activity was commercially viable and could spread risk, particularly in seasons where juice contracts were limited. Non-premium grade fruit will be supplied to the same proprietor in 2017/18.

Trials with 4.5 kg non-premium fruit trays marketed by Woolworths as 'Odd Bunch Honey Gold' resulted in 7,500 and 31,000 trays sold during the 2015/16 and 2016/17 seasons, respectively. The line utilised fruit that otherwise was sold as a loose 15 kg bulk pack in the central wholesale markets. It also proved to be an efficient line to process at sheds as it was packed and sold in a standard 'mod 12' tray. In 2017, Woolworths paid an average of \$2.70/kg for the Odd Bunch fruit, a much higher return than has previously been achieved for this grade of fruit. The line has been confirmed for the 2017/18 season. In the 2016/17 season, Harris Farm Markets purchased 34,000 cartons of a 15 kg bulk fruit grade at \$2/kg for their 'Imperfect Picks' line. This was the highest pricing ever achieved for this grade of 'Honey Gold' fruit. The fruit were packed loose into cartons and delivered green to Harris Farm Markets for ripening. This reduced Piñata Farm's ripening costs, increasing their returns and simplifying logistics. Harris Farm Markets have committed to buying all of the bulk grade fruit for the 2017/18 season.

Based on recommendations by Piñata Farms, Coles and Woolworths refined their premium 'Honey Gold' fruit grade specifications to allow a higher tolerance of fruit with minor skin defects. Following a successful trial, the new specifications were recently adopted by the Australian mango industry to extend to other varieties. This approach will continue for the 2017/18 season. 'Honey Gold' growers reported greater packing efficiency with shed staff only required to be trained to pack two grades of fruit (premium + class 1, bulk) instead of three (premium, class 1, bulk) for these retailers.

Piñata Farms worked closely with Coles and Woolworths to trial marketing a reduced range of fruit sizes to different states. For example, fruit sizes 14-20 were sold in Queensland stores, while sizes 9-14 were marketed in New South Wales. This simplified logistics for Piñata Farms when sending out orders. It also enabled Piñata Farms to market the entire spectrum of fruit sizes (i.e. 9-20) to these major retailers. This approach will continue in following seasons.

Evaluation and Discussion

Effectiveness of project activities

Outputs were delivered in post-season progress reports, post-season review meetings and presentations at mango industry and 'Honey Gold' grower conferences. These were well received by Piñata Farms and their growers who were excellent collaborators, as evidenced by their willingness to contribute resources to evaluate and capitalise on potential opportunities.

Experiments were completed with Piñata Farms and their growers. The project collaborators were directly involved in planning, executing and assessing field (e.g. irrigation, nutrition, diurnal harvest) and transport (e.g. inserts) experiments. They contributed staff and organised logistics to ensure experiments ran according to plan. This ensured project activities considered commercial issues, were adequately resourced and provided the collaborators with insight into outcomes as they emerged. The rapid uptake and positive commercial impact of night harvesting by Northern Territory 'Honey Gold' growers to reduce USB reflected effective project work and sharing of information.

Project feedback

Pre-season planning and post-season review meetings were held each year with Piñata Farms to provide updates on project progress and seek feedback. Project findings were discussed with the 36 contracted 'Honey Gold' growers at annual Honey Gold Congresses. More generic findings were shared with the mango industry at a national conference and through the publication of four articles in industry journals. Project outputs generated positive feedback and greater awareness of opportunities to improve practice.

Input provided by Piñata Farms and their growers greatly benefited the project. It helped to prioritise activities and guide experiment design by ensuring practical and commercial imperatives were considered and incorporated. The inclusion of two PhD students from The University of Queensland in the project accelerated research progress and improved the quality of outputs. The student programs ensured that experiments involved appropriate scientific rigour. Feedback from regular meetings with the students and university collaborators helped the project team understand the biological basis of fruit responses and, in turn, identify alternative approaches and treatments for testing.

Changes resulting from the project

The major discovery in this project was that night-harvesting 'Honey Gold' mangoes could reliably reduce fruit sensitivity to USB development. These findings prompted the largest 'Honey Gold' grower in the Northern Territory to harvest most of their Katherine crop at night in 2014/15. By the 2015/16 season, all 'Honey Gold' growers in the Northern Territory harvested their fruit at night. Gavin Scurr, Managing Director of Piñata Farms, described the commercial impact of this change in practice:

"Before the start of the project, our losses due to USB were up to 20% of our Northern Territory crop. Since initiating the project, we have adopted the recommendations and have reduced our USB losses to below 1%. As well as harvesting at night, we have designed and built a harvest aid to carry fruit with conveyer belts to the baths due to the outcomes of this project."

Significant additional benefits have been realised from commercial night harvesting, including less stress on both pickers and machinery, lower fruit harvest temperatures, greater picking efficiency and a 20% increase in picking speed. Overall, the change to night harvesting has resulted in greater profitability for Piñata Farms and their Northern Territory growers. Over the six to seven mango seasons prior to extensive night harvesting, all 'Honey Gold' fruit consignments from the Northern Territory had to be re-sorted and downgraded at the markets due to USB, with an estimated annual loss in revenue of \$600,000 to \$1 million.

The current project also supported a formal downgrade analysis of 'Honey Gold' fruit by ripeners in the central markets. After viewing their downgrades analysis results and advice from the project team, many 'Honey Gold' growers implemented improved practices (e.g. improved orchard spraying, pruning, nutrition). This translated into a significant overall increase in fruit yield and quality during the 3-year project. For example, the proportion of the total packout that was bulk grade fruit decreased from 26% to 21% over the past 3 years. The resulting 5% increase in the packout of premium fruit was vital for improving farm returns.

Midway through the project, Piñata Farms negotiated with retailers, Coles and Woolworths, to revise 'Honey Gold' fruit grading standards to accept premium fruit with minor skin defects. At an end of season review, growers reported that the new simplified grading system resulted in greater packing efficiency. Coles and Woolworths also agreed to market a reduced range of 'Honey Gold' fruit sizes to each state. This enabled Piñata Farms to streamline logistics and reduce waste by selling all fruit sizes because the states had differing size preferences.

Project learnings and relevance

The project verified that USB development on 'Honey Gold' fruit was related to harvest time during the diurnal cycle. The discovery that harvesting fruit at night significantly reduced sensitivity of fruit to developing USB was a major breakthrough. Night harvesting is the most reliable management tool identified so far across three projects (MG06022, MG10009, MG13016) to reduce the occurrence and commercial impact of USB. By working closely with the project collaborators, there was rapid adoption of night harvesting by growers, ensuring the associated commercial benefits were readily realised. The project also identified 'Lady Jane' and 'R2E2' mango as being highly and moderately susceptible, respectively, to USB. Thus, the benefits of night harvesting and other previously identified practices for minimising USB (e.g. slow pre-cooling to 16°C, careful handling) would be relevant to these other varieties. Other benefits of harvesting fruit during the cooler periods at night included lower fruit temperatures, and thus less field heat to remove during pre-cooling, and more efficient picking by harvest crews. This should be of interest to the broader mango industry in northern Australia.

The association of physical damage with USB identified another major control strategy. Reducing physical damage during transport did not realise major benefits in the current project. However, the research suggested that changing the characteristics of the tray base may reduce fruit vibration. It is planned to explore this further through an Australian Research Council-Linkage grant with the Victoria University of Technology.

The project identified several approaches for reducing red lenticel damage in 'Honey Gold' fruit. Pre-harvest bagging to reduce red skin and lenticel colour and postharvest exposure to blue light to enhance blush development and mask lenticels were among promising leads. These preliminary findings warrant further R&D to assess potential commercial efficacies and benefits. For example, the use of bagging as a commercial option would need to take into account the costs, time commitment and the associated

reduction in blush on the fruit. The use of blue light to enhance fruit blush, a characteristic sought after by consumers, may be of interest and relevance to growers of other mango varieties, but further development is required.

The current crop forecasting model for 'Honey Gold' was demonstrated to be particularly robust and accurate. The heat sums forecasting model has been tested on other mango cultivars and applied more extensively in the Northern Territory using slightly differing parameters.

Alternative software to efficiently record and report fruit downgrade analysis was tested by a 'Honey Gold' ripener. Feedback on fruit quality and reasons for any downgrade via this process was well received, with many growers implementing improved practices (e.g. improved orchard spraying, pruning, nutrition) to correct fruit quality defects. This translated into a significant overall increase in fruit yield and quality during the 3-year duration project. Of interest, few growers completed formal downgrade analysis at their pack sheds, citing issues with available time and resources. Instead, most growers felt they could get a good idea of fruit quality issues by casual inspections at grading. Further work is required to encourage greater adoption of downgrade analysis along the whole supply chain. This is an ongoing issue for the mango industry.

Several alternative products and uses for non-premium 'Honey Gold' fruit were identified, trialled and successfully marketed during the project. This included relaxing the premium grade specifications to accept fruit with minor skin defects, developing a non-premium fruit product line, and contributing fruit to a frozen processed mango product. While acceptance of more relaxed quality standards is being extended to other Australian mango varieties, there are key learnings from the approaches used in this project for better utilisation of non-premium fruit to reduce waste and increase farm profitability. Taken overall, the desire of Piñata Farms and their growers to adopt improved farm and business practices highlights and confirms the potential benefits to the wider industry to enhance fruit quality outcomes.

Recommendations

Activity 1: Reducing USB

Adoption of current project recommendations has reduced the commercial impact of USB. The following recommendations reflect the large body of incremental experiment work and findings from projects MG06022, MG10009 and MG13016. They are relevant to 'Honey Gold' fruit produced in hot tropical climates, but could be extended to other susceptible mango varieties such as 'Lady Jane' and 'R2E2'.

Recommended practices for reducing the commercial significance of USB are:

- Harvest fruit at night between about 10 PM and 6 AM.
- Reduce physical damage to fruit by careful harvesting, packing into soft but supportive tray inserts, and transporting fruit in trailers with air bag suspension.
- Delay pre-cooling for 1-2 days after harvest and slowly reduce fruit temperatures to 16°C.
- Transport fruit at 16°C.

Further R&D is required to identify the underlying causes of USB in order to grow more robust fruit and prevent expression of the defect. Development and evaluation of cost effective practices (e.g. improved tray inserts, strengthened trays, pallet liners) is also needed to minimise transport vibration and fruit damage associated with increased USB expression. There is also an opportunity to consolidate current recommendations into a best practice guide for sharing with growers and supply chain partners.

Activity 2: Reducing red lenticel

The current project identified pre- and postharvest treatments with potential to reduce red lenticel damage on 'Honey Gold' mango. Additional follow-on R&D will be crucial to refine treatments with a view to implementing improved practices for reducing red lenticel. While the following recommendations have a focus on 'Honey Gold' fruit produced in cool and wet sub-tropical districts, they may have broader benefits to the whole Australian mango industry, particularly methods to enhance fruit colour.

Preliminary recommendations to reduce the development of red lenticel damage are:

- Pre-harvest bagging of fruit to block sunlight and decrease red pigment / blush development.
- Postharvest exposure to blue LED lights to enhance blush and potentially mask red lenticels.

The use of bagging as a commercial option would need to undergo cost-benefit analysis to account for the costs, time commitment and impact of the associated reduction in blush on fruit marketability. More experimentation is required on higher intensity blue LED lights, different wavelength specificities and the potential for deployment of light treatments in the field. Portable rainout shelters could also be evaluated for their ability to protect fruit against rain prior to harvest and potentially reduce USB.

Activity 3: Crop Forecasting

- Continued use of the forecasting model that relies on 1500 accumulated heat units from full flowering to predict time of fruit maturity and first harvest.
- Cross-checking of the predicted harvest date against external and internal indices of fruit maturity.
- Inclusion of a mid season heat sum estimation to help account for hotter or cooler seasons and fine tune the forecasted harvest dates.
- Greater coordination of data collection and analysis by Piñata Farms.
- Use of minimal intervention data loggers to automatically upload temperature data to a central site.
- Refinement of the Microsoft® Excel™ file to improve efficiency of data entry and interpretation.
- Consider integrating the heat sums model with the Australian Mango Industry Association focus to reduce immature fruit harvesting using near infrared spectroscopy and in-market maturity testing. This could provide a more integrated approach to crop forecasting across the industry.

Activity 4: Downgrade analysis

- Continued encouragement of growers and chain partners by Piñata Farms to adopt formal fruit quality downgrade analysis, highlighting the potential benefits for increased returns.
- Continue to gather and review downgrade analysis data from growers to diagnose quality issues and, in turn, advise on improved practice to enhance fruit quality for seasons to come.
- Further testing of alternative software such as Muddy Boots® to simplify the downgrade analysis and reporting interface and make it more user-friendly.

Activity 5: Non-premium products

- Annual evaluation of the commercial viability of current non-premium fruit products and markets.
- Continuous scanning of the market for other prospects to utilise non-premium fruit products.

Scientific Refereed Publications

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Intellectual Property/Commercialisation

No commercial IP generated.

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Appendices

- Appendix 1. Meta-analysis of multi-season data on susceptibility of 'Honey Gold' mango to USB.
- Appendix 2. Diurnal effects on USB: 2013/14 season report.
- Appendix 3. Diurnal effects on USB: 2014/15 season report.
- Appendix 4. Comparing USB susceptibility in various mango cultivars.
- Appendix 5. Tray inserts and USB: 2013/14 season report.
- Appendix 6. Comparison of two liner types on the development of USB.
- Appendix 7. Tray liner effects on physical damage resulting from vibration simulation.
- Appendix 8. Tray liner effects on the development of USB caused by vibration during road freight.
- Appendix 9. Effects of vibration and temperature on 'Honey Gold' mangoes.
- Appendix 10. Laboratory testing of pallet damping systems to reduce transport damage.
- Appendix 11. Testing of pallet damping systems in commercial refrigerated transport.
- Appendix 12. Irrigation effects on USB: 2014/15 season report.
- Appendix 13. Irrigation effects on USB: 2015/16 season report.
- Appendix 14. Nutrition effects on USB: 2014/15 season report.
- Appendix 15. Nutrition effects on USB: 2015/16 season report.
- Appendix 16. Effects of methyl jasmonate, salicylic acid and oxalic acid on USB: 2015/16 season report.
- Appendix 17. Effects of methyl jasmonate and oxalic acid on USB: 2016/17 season report.
- Appendix 18. Rootstock and soil type effects on USB.
- Appendix 19. Effects of Photon[®] treatment on USB.
- Appendix 20. Potential treatments to reduce red lenticel on 'Honey Gold' mango: 2015/16 season report.
- Appendix 21. Potential treatments to reduce red lenticel on 'Honey Gold' mango: 2016/17 season report.
- Appendix 22. Verification of a crop forecasting model for 'Honey Gold' mango.



**Analysis of combined multi-season data
on the under skin browning (USB) of
'Honey Gold' mango**

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Pip Bryant, Bob Meyers, Peter Hofman, Ted Winston, Daryl
Joyce

(2014/15)



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Summary

Over several seasons and across multiple farms and regions, more than 40 experimental trials have been undertaken investigating under skin browning (USB) in 'Honey Gold' mangoes. With the accumulation of such large volumes of information, it was considered timely to combine the data sets, and study the overarching patterns and relationships in the data. The data were collated for analysis from multiple research trials carried out over 4 mango seasons (2011/12 to 2014/15) using fruit from 7 farms in various regions.

Preliminary analysis showed that two different methods of applying an abrasion injury to the fruit, namely dragging the fruit over sandpaper, or using an orbital sander, were comparable. This allowed the data from experiments using varied abrasion techniques to be combined for analysis. However, fruit treated by commercial handling and road freight to southern markets without an abrasive treatment showed lower incidence of USB, and were excluded from the analysis.

The overarching effect of the time of harvest on USB incidence was most striking. The collation of data across all seasons and regions showed a distinct peak in USB incidence in fruit harvested at 12-2pm. The collated data strongly confirmed trends already observed in trials specifically designed to examine the effect of time of harvest over 24 hours on USB. Grouping fruit into 6 hour time of harvest brackets across the day (6am-12pm and 12pm-6pm) showed that, within and across seasons, USB incidence was consistently higher in fruit harvested in the afternoon compared with the morning. This 6 hour grouping was added to subsequent analyses to attempt to isolate and remove this effect when analysing sets of data harvested at various times during the day.

The environmental conditions at the time of harvest showed a significant relationship with USB incidence. Higher temperature, lower relative humidity (RH) and higher vapour pressure deficit (VPD) at harvest were associated with increased incidence of USB. In contrast, longer term environmental conditions, over the weeks or months prior to harvest, did not appear to influence USB.

Between season differences were significant, with the 2014/15 season showing the highest incidence of USB. It was thought that this may have been primarily due to extreme environmental conditions at the time of harvest in this season.

Across the 4 seasons studied, the Northern Territory (NT) growing region showed overall significantly higher incidence of USB than the far North Queensland (FNQ) region. This regional difference was linked with higher VPD at the time of harvest.

Two nearby farms from the Katherine district, (NT), Dean's and Fox Road were compared. While Dean's farm had typically shown lower levels of USB over the years than Fox Road, an unexpectedly higher incidence was shown in the 2014/15 season. The two farms showed similar environmental conditions at harvest within each season, with more extreme conditions in the 2014/15 season than in previous seasons. It was hypothesised that the cumulative effect of various stresses on USB incidence may have resulted in this differing response between the two farms.

Overall, analysis of the combined data set confirmed the strong effect of time of harvest on USB incidence. The environmental conditions on the day of harvest were one of the key factors determining susceptibility to USB. Where possible, it is recommended that harvest under very hot and dry conditions be avoided to reduce the risk of the disorder.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, small seed size and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Under the Piñata/HAL projects MG06022 and MG13016, more than 40 various trials have been carried out investigating the causes of USB. It has been established that the disorder is associated with the combination of hot growing climate, physical injury and storage at cool temperatures. Fruit susceptibility is usually higher in fruit from tropical production areas around Darwin and Katherine (NT) and less in fruit grown at higher altitudes inland from Cairns (Qld), such as the Atherton Tablelands. It has not been detected in subtropical production areas from Bowen (Qld) south.

A survey carried out at multiple farms across various growing regions established that USB susceptibility also varied between individual farms within each region. The different responses of fruit from two farms in the Katherine region within 15km of each other were highlighted as an interesting comparison.

It was discovered that 'Honey Gold' fruit harvested at night and early morning were less sensitive to USB than those harvested in the afternoon. The resultant adoption of night-harvesting at a Katherine farm in the 2014/15 season proved beneficial in reducing incidence of the disorder under commercial conditions.

Numerous trials have also been undertaken exploring conditioning treatments, types of packaging, fruit characteristics, nutrition treatments, field practices, irrigation treatments, rootstocks and soil types. The current study aims to collate the previous research in order to study the overarching patterns and relationships in the data across multiple seasons and regions.

Materials and Methods

Data were collated for analysis from multiple research trials carried out over 4 mango seasons (2011/12 to 2014/15). Fruit were harvested from 7 farms in various regions, including the Northern Territory (NT), far north Queensland (FNQ), and north Queensland (NQ) (Table 1). While the experimental data included additional farms from central Queensland (CQ) and southeast Queensland (SEQ), these could not be included in analyses due to no USB being detected in fruit from these farms.

Table 1. Farms included in the combined multi-season data set. NT= Northern Territory, FNQ = far north Queensland, NQ = north Queensland, CQ = central Queensland and SEQ = south east Queensland.

Farm	Region	Location
Fox Road (Pinata)	NT	Katherine
Dean's	NT	Katherine
Mataranka (Pinata)	NT	Mataranka
Hayes	NT	
Cetinic	FNQ	Mareeba
Zugno	FNQ	Mutchilba
Williams	NQ	Bowen
Rockhampton (Pinata)	CQ	Rockhampton
Wamuran (Pinata)	SEQ	Wamuran

Fruit were harvested by hand, and were typically de-sapped in Mango Wash[®] and allowed to dry. The fruit were then abraded at four locations around the largest circumference of the fruit. The abrasion was applied either by dragging fruit across a sheet of sandpaper, or by using a small Ozito orbital finishing sander for 2 sec at a speed setting of 4-5 (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. After abrasion, the fruit were stored at cool temperatures (12-14°C) for at least six days, and then typically transported to SEQ by road freight at 12-16°C. The fruit were ripened at 20°C, with ethylene as required, until near eating soft. Fruit were then assessed for symptoms of USB.

Assessment of USB included the use of scoring systems, measurements of area, and records of incidence. A preliminary scoring system was used in early experimental work, but this system could not be converted to the later scoring system, and so was not included in the analyses. The scoring system used in analyses was a 0-5 scale based on estimated area of USB:

- 0 = nil,
- 1 = up to 1 cm²,
- 2 = 1 to 3cm²,
- 3 = 3 to 12cm²,
- 4 = >12cm² (approximately 10%) and <25%,
- 5 = >25% of the fruit surface area affected.

In some cases, the USB was assessed by measuring the approximate area of discolouration. The width and breadth of the abrasion site, and of the USB discolouration (including the abraded area) were measured separately, and the area of each calculated as an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Where necessary, USB area could be converted to determine USB scores, using the score scale above.

USB was also observed on areas of the fruit that were not abraded with sandpaper. These were assumed to have been caused by normal commercial practices from packing onwards. These background USB symptoms were also recorded, and measured for incidence, score or area as described above.

Most analyses in this report were carried out on the incidence of any USB on individual fruit, which included symptoms induced by abrasion or occurring as background USB.

In May/June 2011 Tiny Tag data loggers (Ultra 2 Internal Temperature and Tiny Tag Plus with tipping bucket rain gauge) were installed within most orchards in the study. Temperature and RH data were collected at 15 minute intervals, and rainfall at hourly periods.

To determine the percentage dry matter (%DM), 6-10 average fruit were collected. For each fruit a section was taken from the cheek and grated or diced. Samples were dehydrated using an Ezidri D09H food dehydrator at 60°C until at a constant weight.

Analysis

Data were analysed using GENSTAT® 16 for Windows™ (VSN International Ltd., UK). Analyses of farm and seasonal effects were carried out by REML analysis using a fixed model with 6h time of harvest brackets included as a factor. Where time of harvest could not be determined, data were excluded from these analyses. Time of harvest and environmental variables were analysed by ANOVA. Each data point analysed was an incidence value from within a *Season x Farm x Experiment x Treatment x Time of harvest bracket* group (referred to as 'grouped data'). Significant differences between means were determined by LSDs at p=0.05.

Results and Discussion

Methods of applying physical damage

Physical damage to the fruit has been linked with the development of USB symptoms in Honey Gold mangoes. The application of physical damage was used in trials to elicit the USB response. Three principle techniques were used during the experiments to apply the physical injury:

1. Dragging the fruit across sandpaper.
2. A standard abrasion test, with an orbital electric sander lowered onto the fruit for about 2 sec.
3. Fruit sent by road freight under commercial conditions to southern markets, typically about 3 days.

Preliminary analysis comparing the different methods of applying mechanical damage showed that the methods involving sandpaper or the orbital sander did not significantly differ. However, fruit treated by road freight alone (often in commercial trials) showed a significantly lower incidence of USB than fruit treated by abrasion (data not shown) because of less severe physical damage following transport. Experiments involving abrasion by sandpaper or orbital sander were combined for analysis, while the road freight treated fruit were removed. There was insufficient data to analyse the road freight treated fruit separately.

Diurnal Effects

The time of day at harvest has previously been shown to affect the USB response. Preliminary analysis of the combined data confirmed a very strong effect of the time of day at harvest on the incidence of USB. Data sets were analysed within 2h, 4h and 6h diurnal time brackets. Summarising the data (from measurements on individual fruit) across all seasons grouped within 2h time of harvest brackets revealed a distinct peak in USB in fruit harvested at 12-2pm (Figure 1). This peak was also seen within each season, although there were some outliers in the pattern (data not shown).

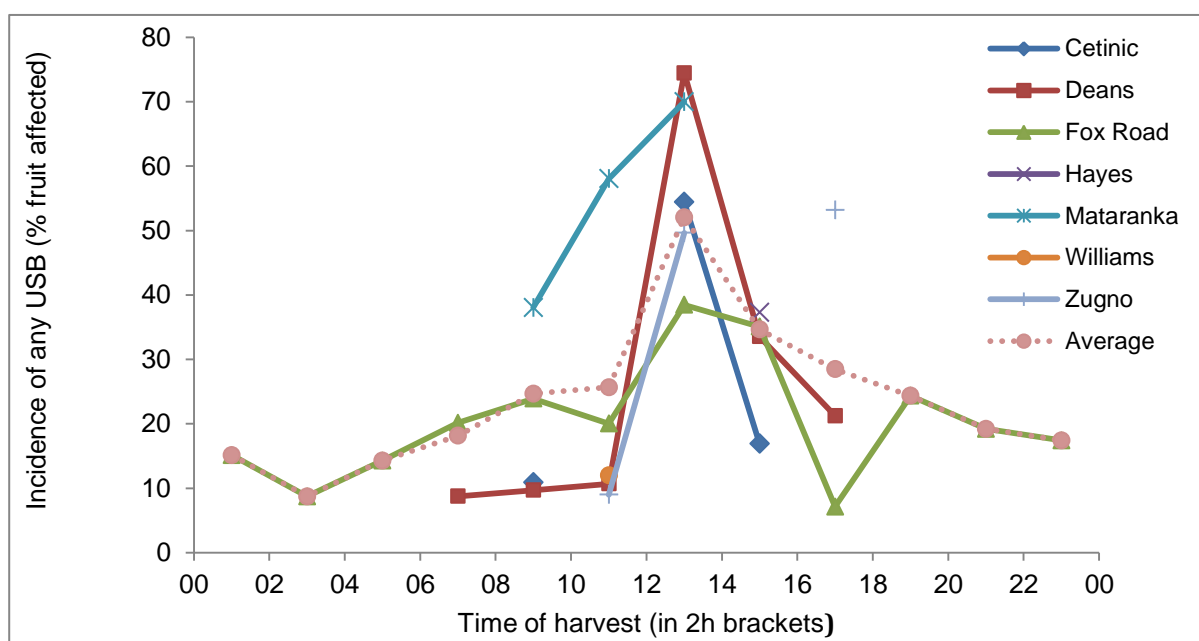


Figure 1. USB Incidence over a range of harvest times (in 2h brackets) at various farms, using combined data of individual 'Honey Gold' fruit from 4 seasons (2011/12 to 2014/15).

Analysis of grouped data showed that fruit harvested in the morning had significantly lower USB incidence than those harvested in the afternoon (Table 2). While USB incidence tended to decline later in the afternoon, the time brackets of 12-2pm, 2-4pm and 4-6pm did not significantly differ. The limited data available in overnight time brackets (6pm to 6am) precluded analysis of these time periods. Previous diurnal trials showed USB levels were typically low overnight, as reflected in Figure 1. These results confirm the strong effect of time of harvest on USB incidence shown in the trials designed to determine the effects of diurnal harvesting.

Table 2. Effect of time of harvest (in 2h brackets) on incidence of any USB in 'Honey Gold' mangoes from various regions (NT, FNQ and NQ) over four seasons (2011/12 to 2014/15).

Time of harvest (2h brackets)	Incidence of any USB (% of fruit)
6-8am	27.0 ^{bd}
8-10am	29.2 ^{cd}
10am-12pm	26.7 ^{cd}
12-2pm	60.8 ^a
2-4pm	49.7 ^{ab}
4-6pm	37.2 ^{abc}

Data analysed by ANOVA ($p < 0.001$, $n = 2-33$). Means with the same letter are not significantly different at $p = 0.05$, as tested by LSD.

When the data were grouped into 6h time brackets across the day, the incidence of USB showed a very consistent pattern across seasons. For all farms, grouped within each season, and across all seasons, the average incidence of USB was consistently higher in the afternoon (12-6pm) than in the morning (6am-12pm) (Figure 2). Average values of USB incidence across all farms and seasons were 28.6% in the morning, and 54.6% in the afternoon, with a significant difference shown (ANOVA $p < 0.001$). Due to the strong effect of time of harvest, the 6h time bracket was included as a factor in all subsequent analyses.

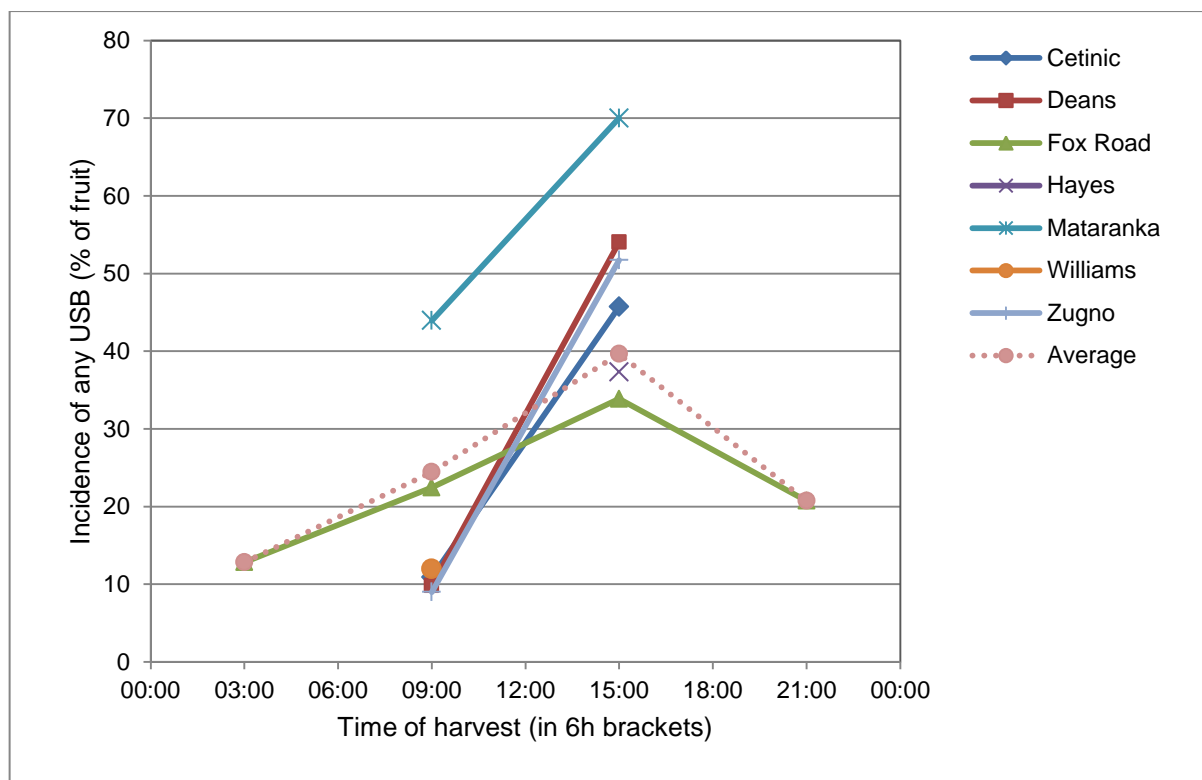


Figure 2. USB incidence over a range of harvest times (in 6h brackets) at various farms, using combined data of individual 'Honey Gold' fruit from four seasons (2011/12 to 2014/15).

Environmental Conditions

Environmental conditions such as rainfall, temperature and relative humidity (RH) can strongly influence fruit growth and characteristics, and were tested to determine if any relationships could be detected between these conditions and USB incidence. Various parameters were tested, including:

- **Temperature (°C):** Average minimum, maximum and temperature range in the 3 weeks prior to harvest; absolute maximum temperature in the week prior to harvest; temperature at the time of harvest; fruit temperature at harvest (where measured).
- **RH (%):** Average RH in the 3 weeks prior to harvest; RH at the time of harvest.
- **Vapour pressure deficit (VPD) (Pa):** VPD in the 3 weeks prior to harvest, VPD at the time of harvest.
- **Rainfall:** Total rainfall from Stage i to harvest (mm); Number of wet days (≥ 0.2 mm) from Stage i to harvest; Total rainfall in 3 weeks prior to harvest (mm); Rainfall on harvest day (mm).

The temperature, RH and VPD conditions at the time of harvest showed moderately strong correlations with USB incidence (Table 3). Higher air temperature and lower RH at harvest were associated with greater incidence of USB. VPD, an indicator of the capacity of the air to pull moisture from the tree, is calculated from temperature and RH, and all 3 variables are strongly correlated with each other. For example, for the data set collected at harvest, a higher air temperature was very strongly associated with a lower RH (Spearman correlation coefficient -0.954, $p < 0.001$). These environmental parameters are also

obviously strongly linked to time of day, with higher temperatures occurring in the early afternoon, when USB incidence is highest. While data was limited, the analysis of USB area and score in affected fruit showed the same pattern of correlation with temperature, RH and VPD at harvest (data not shown). As shown in incidence data, USB area and score tended to be more severe in more extreme drying conditions. The rainfall variables and longer term environmental variables analysed did not show any significant correlation with USB incidence. It appears that the environmental conditions at the time of harvest could be a critical factor influencing USB development.

Table 3. The correlation between environmental parameters and incidence of any USB (%) in grouped data from various regions (NT, FNQ and NQ) over four seasons (2011/12 to 2014/15).

Environmental parameter	Spearman correlation coefficient	p-value
Air temperature (°C) at the time of harvest	0.604	< 0.001
RH (%) at the time of harvest	-0.594	< 0.001
VPD (Pa) at the time of harvest	0.607	< 0.001

Seasonal differences

The 2014/15 season showed significantly higher incidence of USB in the NT than the previous two seasons (REML $p < 0.001$) (Table 4). This was consistent with the more extreme harvest conditions of significantly higher temperature and lower RH, and resultant higher VPD in the 2014/15 season.

As the research on USB progressed, the strong diurnal effect on USB became apparent. In the later seasons, particularly the 2014/15 season, it became common practice to aim to harvest fruit in the early afternoon, to induce higher levels of USB, and hence be able to observe treatment effects more clearly. In 2014/15 almost all trials were harvested between 1-2:30pm. While the 6h time bracket factor included in the analysis takes an am/pm difference into account, it may not have been strong enough to adjust for this cluster of fruit picked at the hottest time of the day. The single 2014/15 data point available from a morning harvest (8:30am) shows much lower incidence of USB (38.8%), which is more representative of the levels in previous seasons. While a significant seasonal variation is shown in the NT, it seems likely that this effect is a relic of tightly clustered harvest times in 2014/15 at the hottest time of the day.

Table 4. Incidence of USB and environmental conditions at the time of harvest across three seasons in Northern Territory fruit.

Season	Incidence of any USB (%) - mean adjusted by 6h bracket time of harvest factor	Incidence of any USB (%) - unadjusted mean	Average air temperature at time of harvest (°C)	Average RH (%) at time of harvest	Average VPD at time of harvest (Pa)
2012/13	43.2 ^a	38.4	30.6 ^a	65.0 ^a	1681 ^a
2013/14	31.9 ^a	29.7	32.5 ^a	57.4 ^a	2438 ^a
2014/15	51.8 ^b	61.4	37.8 ^b	37.4 ^b	4170 ^b

USB incidence analysed by REML, with 6h time of harvest brackets included in the analysis. Environmental data analysed by ANOVA ($p < 0.001$, $n = 10-49$ for all analyses). Means with the same letter within each column are not significantly different at $p = 0.05$, as tested by LSD.

The FNQ data was too limited to allow for analysis of seasonal differences within FNQ.

Regional differences

Analysis of regional differences was limited to NT and FNQ regions. Data from central Queensland and SEQ were not included in the analysis, as all data collected from these areas showed no USB. North Queensland data could not be included, as only one data point was available with a time of harvest recorded. With time of harvest taken into account (in 6h brackets), the overarching difference between NT and FNQ was not significant (REML $p = 0.065$). However, the analysis was weakened by limited data, with sample sizes as low as $n = 2$.

Excluding season effects from the analysis, a significant difference between NT and FNQ was detected, with NT showing higher incidence of USB than FNQ (REML $p = 0.032$) (Table 6). This also corresponded with significantly higher VPD in the NT, when VPD was adjusted for time of harvest (REML $p = 0.028$).

Table 5. Incidence of USB and environmental conditions at harvest in far North Queensland (FNQ) and Northern Territory (NT) across four seasons.

Season	Region	Incidence of any USB (%) - mean adjusted by 6h bracket time of harvest factor	Incidence of any USB (%) - unadjusted mean	Average air temperature (°C) at time of harvest	Average RH (%) at time of harvest	Average VPD (Pa) at time of harvest
2011/12	FNQ	42.2 ^{ab}	53.8	33.2 ^{ab}	58.1 ^{ab}	2159 ^{bc}
2011/12	NT	*	*	*	*	*
2012/13	FNQ	19.3 ^a	23.2	31.9 ^b	60.9 ^a	2005 ^{bc}
2012/13	NT	43.4 ^b	38.4	30.6 ^b	65.0 ^a	1681 ^c
2013/14	FNQ	24.1 ^{ab}	12.5	31.3 ^b	66.9 ^a	1561 ^{bc}
2013/14	NT	29.7 ^a	29.7	32.5 ^b	57.4 ^a	2438 ^b
2014/15	FNQ	*	*	*	*	*
2014/15	NT	51.4 ^b	61.4	37.8 ^a	37.4 ^b	4170 ^a

USB incidence analysed by REML, with 6h time of harvest brackets included in the analysis. Weather data analysed by ANOVA ($p < 0.001$, $n = 2-49$ for all analyses). Means with the same letter within each column are not significantly different at $p = 0.05$, as tested by LSD.

Table 6. Variation in USB incidence and VPD at harvest in FNQ and NT across four seasons (2011/12 to 2014/15).

Region	Incidence of any USB (%) - mean adjusted by 6h bracket time of harvest factor	Incidence of any USB (%) - unadjusted mean	Average VPD (Pa) at time of harvest - mean adjusted by 6h bracket time of harvest factor	Average VPD (Pa) at time of harvest - unadjusted mean
FNQ	27.0 ^a	28.9	1749 ^a	1922
NT	43.2 ^b	41.6	2398 ^b	2278
(LSD)	(14.8)		(575)	

Analysed by REML, with 6h time of harvest brackets included in the analysis ($n = 7-73$, for USB incidence $p = 0.032$, for VPD $p = 0.028$). Means with the same letter within each column are not significantly different at $p = 0.05$, as tested by LSD.

Comparison of two NT farms

Two farms situated within 15 km of each other in the Katherine district, NT, have shown noticeable differences in USB incidence. In the 2011/12 to 2013/14 seasons (data not shown for 2011/12), Dean's fruit showed consistently lower USB incidence than Fox Road and this trend was confirmed in commercial shipments. In the 2014/15 season, Dean's farm showed an unexpectedly high incidence of USB, which did not significantly differ to Fox Road levels (Table 7). USB incidence at Dean's in 2014/15 was significantly higher than in previous seasons on the same farm (with am/pm differences in time of harvest taken into account).

Harvest conditions were more extreme in the NT 2014/15 season compared with other seasons, with higher temperatures, lower RH and higher VPD at harvest (Table 7) (ANOVA, $p < 0.001$ for all analyses). These environmental conditions at harvest were significantly correlated with USB incidence in the Katherine region, as was previously shown across all regions (data not shown). The effect of environmental conditions at harvest would, to some extent, be taken into account in the analysis by the inclusion of the harvest time effect, as these environmental conditions are strongly linked to time of harvest. However, as previously mentioned, the fruit from the 2014/15 season were highly clustered in the timing of harvest, between 1-2:30pm. This may have resulted in the 6h time bracket adjustment not being strong enough to remove the diurnal effect. The two farms did not significantly differ in temperature, RH and VPD at the time of harvest in 2014/15, suggesting that other factors have contributed to the different responses between Dean's and Fox Road farms.

It could be hypothesised that the various stresses associated with USB (extreme environmental conditions / water stress; physical stress; chilling stress) have a cumulative effect on fruit susceptibility to USB. This would make it possible that the more extreme environmental conditions at harvest in 2014/15 contributed to the higher levels of USB at Dean's in this season, by adding to the underlying stress load to the point where USB would be expressed. This hypothesis would assume that Fox Road fruit have a lower stress threshold at harvest, perhaps due to being subjected to other stresses during fruit growth and development. Due to these underlying stresses, the Fox Road fruit could then more readily develop

USB under typical harvest conditions. The less stressful pre-harvest conditions at Dean's could result in fruit capable of tolerating typical harvest conditions. However, the greater stress of extreme environmental conditions at harvest may have been sufficient to trigger the expression of USB symptoms in the Dean's fruit in the 2014/15 season. It has been noted that the Dean's farm has better quality irrigation water and a soil pH of 6-7, compared to pH 8-9 at Fox Road, and that the farms also differ in some management practices. It is possible that these underlying differences between the farms contribute to different levels of susceptibility at harvest.

Table 7. Seasonal and between farm variation in USB incidence, %DM and environmental conditions in two Katherine, NT farms.

Season	Farm	Incidence of any USB (%) - mean adjusted by 6h bracket time of harvest factor	Incidence of any USB (%) - unadjusted mean	Average air temperature (°C) at time of harvest	Average RH (%) at time of harvest	Average VPD (Pa) at time of harvest
2012/13	Dean's	13.7 ^c	6.3	29.0	69.1	1378
2012/13	Fox Road	45.2 ^{ab}	43.5	31.3	63.7	1832
2013/14	Dean's	18.1 ^c	12.6	32.6	60.2	2378
2013/14	Fox Road	41.1 ^b	41.1	32.3	56.3	2421
2014/15	Dean's	57.4 ^a	65.3	37.1	41.5	3880
2014/15	Fox Road	46.3 ^{ab}	57.4	38.0	35.5	4318

Data analysed by REML, with 6h time brackets included as a factor ($p < 0.001$, $n = 4-6$). Means with the same letter within each column are not significantly different at $p = 0.05$, as tested by LSD.

Conclusions

The collation of data from multiple trials has confirmed the strong effect of time of harvest on USB susceptibility. USB incidence was consistently higher in fruit harvested in the afternoon than those harvested in the morning. Environmental conditions at the time of harvest were also shown to influence the incidence of USB, with greater incidence occurring with higher temperature, lower RH and higher VPD. This highlights the importance of avoiding hot dry conditions at harvest to reduce the incidence of USB.

Diurnal harvest effects on USB

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Gavin Scurr, Andrew Macnish, Roberto
Marques, Guoqin Li

(2013/14)



This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, the Department of Agriculture, Fisheries and Forestry.
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Summary

Trials in 2012/13 indicated that 'Honey Gold' fruit harvested in the early morning are less sensitive to under skin browning (USB) induced by a standard test of light skin abrasion followed by cool storage. This provided an exciting lead to reducing USB in commercial consignments that warranted further testing. In the 2013/14 season 'Honey Gold' fruit were harvested every 4-6 h from 10 AM to 2 PM the following day. All of the fruit were abraded within 2 h of harvest, with half the fruit placed at 13°C straight away and the other half held at ambient for another 24 h before storage at 13°C. The results confirmed a strong and consistent effect of harvest time, with fruit harvested at midnight and 6 AM having half the incidence of USB as compared to those harvested between 10 AM and 6 PM. This appeared to be caused by changes in the sap, since sap collected from day-harvested fruit produced more USB-like symptoms when placed back on the fruit than sap obtained from night-harvested fruit. However, this aspect needs further investigation. Also, contrary to previous years a 24 h delay between abrasion and placing at 13°C actually increased USB incidence compared with placing at 13°C as soon as possible after abrasion. These results will be confirmed in commercial trails in 2014/15.

Introduction

Observations from the 2011/12 trials indicated more USB on or near the blush areas of fruit, and on blushed fruit. The development of red blush is considered a protective response of the fruit against the potentially harmful energy from the sun. Hence the hypothesis was developed that under skin browning (USB) is more likely to develop when the fruit are slightly stressed, such as when exposed to the sun on the tree. Also, given that USB appears to be associated with resin canal dysfunction, and maybe the leaking of resin from the canals under pressure, it was possible the more turgid fruit harvested early in the morning were more susceptible to cell and canal rupturing under the pressure of harvest.

To test these hypotheses, preliminary trials were undertaken in 2012/13 by harvesting fruit early in the morning and in mid afternoon from two farms in Katherine. The results indicated a significant and consistent harvest time affect, but contrary to expectations early morning harvest resulted in significantly less USB.

These results suggested a potentially significant commercial benefit to harvesting at night. Therefore, in the 2013/14 season further trials were undertaken to confirm the consistency of this effect, and harvest fruit more regularly during the day and night to identify the harvest times relating to minimum USB sensitivity. These trials were undertaken on one farm in Katherine, with a small trial undertaken on adjacent farm.

Materials and methods

Fruit

'Honey Gold' trees were selected on commercial farms at Fox Rd and Deans in the Katherine area of the Northern Territory. Ten trees were tagged in each of four different rows (replications) on each of the farms. All four rows on the Fox Rd farm were on the same deep sandy loam, while at Deans rows (reps) 1-3 were on red sandy soil on a ridge in the block and row 4 was on hard grey clay soil.

Two fruit were harvested from each tree at each harvest, with one of the fruit per tree abraded and placed at 13°C within 3 h of abrasion, and the other fruit per tree abraded and placed at 13°C after 24 h (see below).

Treatments

The fruit were harvested by hand from the trees at the following times:

Fox Rd:

- 10 AM on Wednesday 13th November
- 2 PM on Wednesday
- 6 PM on Wednesday
- 12 AM midnight
- 6 AM on Thursday 14th
- 2:30 PM on Thursday 14th

The weather was overcast during the afternoon and with light rain in the evening. The 2:30 PM Thursday harvest was included because of the cooler overcast weather on Wednesday and the hotter, more typical afternoon on Thursday.

Deans:

- 4:30 PM on Wednesday 13th

- 7:30 AM on Thursday 14th
- 10:30 AM on Thursday.

All the fruit for each harvest time were harvested within 30 min and abraded using the standard USB method (with orbital sander) within 3 h of harvest. Before abrading the fruit were desapped on a rack with a channel to collect the sap from the 20 fruit per harvest time per replication. The sap was analysed for the concentrations of active ingredients to investigate the mechanisms of the diurnal response.

The surface temperatures of two shaded fruit per tree were recorded using an infrared temperature gun.

After desapping and abrasion, half the fruit per replication were placed at 13°C within 3 h of harvest, and the remainder were left at ambient temperature for a total of 24 h after harvest before being placed at 13°C. All treatments remained at 13°C for a total of 6 d, and were then removed to approx. 20°C and assessed for USB when ripe.

The number of abrasion points on each fruit that developed USB was recorded, and the severity of USB per fruit rated using the following scale:

- 0 = nil
- 1 = less than 1 cm² of skin affected
- 2 = 1-3 cm² (approximately 3%, area of five cent coin)
- 3 = 3-12 cm² (approx. 10% of total fruit area)
- 4 = 12 cm² (approx. 10%) to 25%
- 5 = >25% of the skin effect of the skin affected

Sap effects

To test whether sap characteristics were involved in any diurnal effects, the sap was collected from the 20 fruit per replication per harvest time. A sample of 0.1 mL of either the combined sap, or the upper phase (oil fraction), or of the spirit sap that is released in the first 5 sec after stem removal, or of the ooze sap released in the following 120 sec was placed on small, lightly abraded areas on four points of the harvested fruit and any USB-like symptoms were rated at ripe.

Statistical analysis

There were 10 trees per replication, with one fruit per tree per treatment, and four replications (rows) per harvest. Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), with the 'General Analysis of Variance' model used to analyse the data. In all trials, the least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means.

Results and discussion

Fruit temperatures

Average fruit surface temperatures reached 34-36°C during the day and 24-25°C in the early morning (Table 1).

Table 1 Average surface temperatures of shaded ‘Honey Gold’ fruit at each of the harvest times.

Harvest time	Average fruit surface temperature (°C)
Fox Road	
10:00 AM	32.4
2:00 PM (cloudy)	33.7
6:00 PM	31.9
Midnight	
6:00 AM	24.4
2:30 PM (sunny)	36.1
Deans	
4:30 PM	32.6
7:30 AM	
10:30 AM	25.2

USB

The interaction between time of harvest and delay between abrasion and cooling was not significant. Figure 1 confirms that there was a significant effect of harvest time on USB sensitivity, with fruit harvested between midnight and 6 AM having the least % of fruit with USB of more than 1 cm², and of the percentage of abrasion points that developed USB. This represents a 100% reduction in the percentage of fruit affected. There was no significant difference between susceptibility of fruit harvested in the cooler afternoon on the first day, and the hotter afternoon of the second.

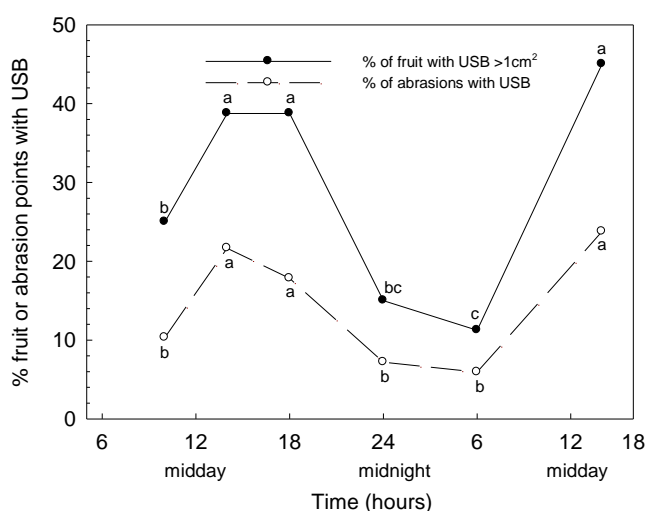


Figure 1 The percentage of ‘Honey Gold’ mango fruit with under skin browning lesions of more than 1 cm², and the percentage of the abraded areas that developed USB, when harvested at different times during the day and night from the Fox Rd farm. Means with the same letters within each measure are not significantly different at P=0.05.

Similar results were obtained with average severity of USB (Table 2), with fruit harvested at midnight and 6 AM have lower average severity compared with fruit harvested at any of the other times.

Contrary to previous season results, delaying for about 24 h between abrasion and placing at 13°C resulted in significantly higher incidence and severity of USB (Table 2), with 18% of fruit having more than 1 cm² of USB if placed at 13°C immediately, compared with 40% if held for 24 h before cool storage. The reasons for the seasonal differences are not clear, but these results need to be tested commercially.

The USB levels were less in Dean's fruit compared with Fox Rd fruit (Table 3), as consistently seen in previous years and trials. There was no effect of harvest time if fruit were placed at 13°C soon after abrasion, but when cooling was delayed for about 24 h the fruit harvested in the afternoon had about four times more USB than those harvested in the early morning.

Table 2 The average severity of USB (0-5) on ripe 'Honey Gold' mango fruit harvested at differing times during the day and subjected to the standard USB abrasion test. Average severity is also presented for the main treatment effects placing at 13°C within 2 h of abrasion, or delaying about 24 h between abrasion and placing at 13°C.

Treatment	Avg. severity of affected fruit (0-5)
Harvest time of the day	
10:00 AM	2.2 ^{ab}
2:00 PM (cloudy)	2.8 ^a
6:00 PM	2.5 ^a
Midnight	1.7 ^b
6:00 AM	1.8 ^b
2:30 PM (sunny)	2.6 ^a
Delay between picking and abrading	
No delay	2.0 ^b
1 d delay between abrasion and 13°C	2.4 ^a

Table 3 The percentage of 'Honey Gold' mango fruit with under skin browning lesions of more than 1 cm², and the percentage of the abraded areas that developed USB, when harvested at different times during the day and night from the Dean's farm. The fruit were either placed at 13°C within 2 h of abrasion, or held for 24 h in the shade before placing at 13°C. Means with the same letters within each column are not significantly different at P=0.05.

Harvest time	% fruit w/ USB >1		% abraded areas with USB	
	No delay	1d delay	No delay	1d delay
4:30 PM	3 ^b	23 ^a	1 ^b	17 ^a
7:30 AM	5 ^b	5 ^b	2 ^b	4 ^b
10:30 AM	5 ^b	0 ^b	1 ^b	1 ^b

Sap effects

Very preliminary analysis suggests that the diurnal USB effects are partly explained by characteristics of the sap (Figure 2). The results suggest that sap from the afternoon fruit produced significantly more USB-like symptoms (Plate 1) when placed on the fruit than sap from the morning. The ooze sap which contains less oil resulted in less damage compared with the spirt sap. Terpinoline is generally the main constituent of the oil fraction, and is also capable of producing similar symptoms as spirt sap and the upper phase of the afternoon sap.

These results will be evaluated in more detail, and chemical analysis needs to be undertaken on the sap samples to confirm composition differences between the sap samples.

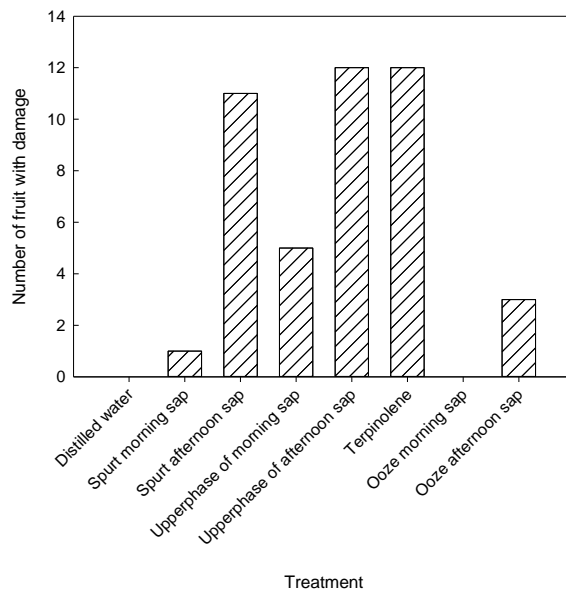


Figure 2 Preliminary results on the number of fruit (out of 12 fruit per treatment) that developed USB-type symptoms when 0.1 mL of sap was placed onto four lightly abraded areas on each ‘Honey Gold’ mango fruit. The sap samples were either from the combined sap, or the upper phase (oil fraction) of the sap, or from the sap that “spurts” from the fruit in the first 5 sec after stem removal, or from the sap that oozes out after 5-120 sec from stem removal, and taken in the early morning or mid afternoon.

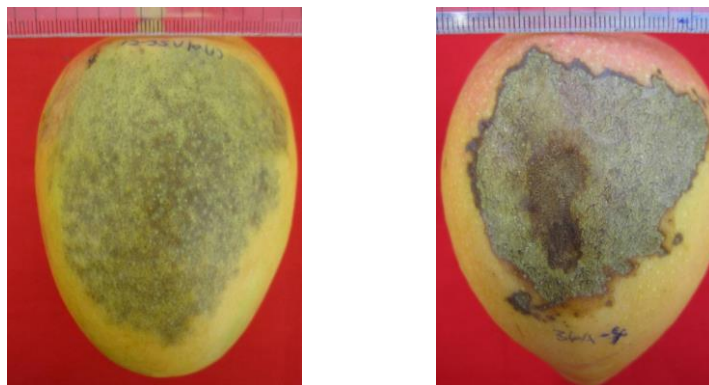


Plate 1 Typical under skin browning (left) and the USB-like symptoms (right) when sap from the diurnal ‘Honey Gold’ fruit were placed onto small abraded areas of the skin.



Diurnal harvest effects on under skin browning of ‘Honey Gold’ mango

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Peter Hofman, Ted Winston, Bhavisha Mehta, Tram San
(Anh), Gavin Scurr

(2014/15)



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Summary

Trials in 2012 to 2014 indicated that 'Honey Gold' fruit harvested at night and early morning were less sensitive to under skin browning (USB) after a standard test of light skin abrasion then placing at 12-14°C for about six days before ripening and assessment. This provided an exciting lead to reducing USB in commercial consignments and resulted in the largest 'Honey Gold' grower night-harvesting most of their 2014/15 Katherine crop. To confirm these R&D results and their implications for commercial harvesting, fruit were harvested every four hours for 24 hours by hand and treated with the USB abrasion test (abrasion with sand paper then holding at 12-14°C for at least six days). Sap was collected from the fruit harvested at different times and 0.1 mL placed on fruit to identify whether sap played a role in the diurnal effects on USB. In addition, fruit were commercially harvested every hour for 24 hours, then commercially packed and transported from Katherine to south-east Queensland.

The results confirmed a strong and consistent effect of harvest time, with fruit harvested at 6 AM having 10% of the fruit with more than 1 cm² USB, compared to about 60% of the fruit harvested at 2 PM. There was little effect of delaying cooling for 24 hours on this percentage, although delaying for 24 hours did reduce the percentage of the abraded sites with USB. USB was also observed on areas of the fruit that had not been abraded, most likely because of physical damage caused during road freight from the Northern Territory to south-east Queensland. The percentage of fruit with more than 1 cm² USB on these non-abraded areas was also significantly lower in fruit harvested at night and early morning compared with those harvested in the afternoon. The commercial trial showed inconsistent USB incidence, possibly due to the constraints on experimental design because of logistical and resource issues.

The sap trials confirmed that sap collected from afternoon-harvested fruit caused more damage to the skin, while sap from morning-harvested fruit resulted in no damage. The upper phase (oil fraction) of the sap was responsible for this damage. Application of 0.1 mL terpinolene and D-limonene (major components of the oil fraction) to the skin resulted in similar and significant damage, while carene resulted in no damage.

These results confirm the potential for night harvesting to significantly reduce USB. Under skin browning incidence in commercial consignments was very low during the 2014/15 season, possibly because of night harvesting. Significant additional benefits have been realised from night harvesting, including less stress on both pickers the machinery, greater efficiency and lower fruit temperatures, so that night harvesting will be standard practice in coming seasons.

Introduction

Trials in 2012/13 indicated that 'Honey Gold' mango fruit harvested in the morning were more resistant to under skin browning (USB) than those harvested in the afternoon. This trial was done with a "USB abrasion test" of wounding the fruit skin with sandpaper and holding at 12-14°C for 5-8 days. More frequent harvesting over 24 hours in 2013/14 confirmed that fruit harvested at night and early morning were more tolerant to USB than those harvested in the late morning and afternoon. Preliminary results suggested this response may be related to characteristics of the sap, with sap from fruit harvested in the afternoon being more likely to cause USB-like symptoms when placed on the fruit, than sap from morning harvested fruit.

The preliminary results need to be confirmed and tested on a commercial scale to determine if the observed effects are sufficiently strong and robust to result in commercial benefit. Also, a better understanding of the mechanisms involved in the diurnal effect may provide insights into additional measures to further reduce USB incidence in commercial consignments.

Hence, two trials were undertaken; confirming last year's results based on replicated harvesting every four hours and applying the standard abrasion test, and simulated commercial harvesting, packing and transport to Brisbane, with fruit harvested every hour for 24 hours.

Materials and Methods

The trial was conducted on block 8-11 at Piñata Farms at Fox Road (Katherine) on 20th of November 2014, and on a commercial farm on Gorge Rd, Katherine (Northern Territory) on 22nd of November.

R&D trial

'Honey Gold' trees were selected on the commercial farms at Fox Rd and Gorge Rd. Ten trees per block were used at both farms.

At Fox Rd, 40 trees of similar visual appearance were tagged in row 2 of the above blocks. Trees 1-10 represented replication one, 11-20 represented replication two and so on.

The fruit were harvested by hand from the trees at the following times:

- 6 AM on Thursday 20th November
- 10 AM on Thursday
- 2 PM on Thursday
- 6 PM Thursday
- 10 PM Thursday
- 2 AM on Friday 21st

Fruit were harvested on the eastern side of North-South running rows. Two fruit were harvested from each tree at each harvest, with one of the fruit per tree abraded and placed at 13°C within 2 hours of abrasion, and the other fruit per tree abraded and placed at 12°C after 24 hours (see below).

The surface temperature of one shaded fruit on the eastern side of each tree at each harvest time was measured with a Ryobi infrared thermometer. The weather was generally fine with some cloud cover in the afternoon.

At Gorge Rd, 10 trees on each of the following blocks (replication) were tagged:

Rep 1	Rootstock HK	Row 4 in block 1
Rep 2	Rootstock PC	Row 5, block 1
Rep 3	Rootstock WC	Row 6, block 1
Rep 4	Rootstock TER	Row 29, trees 9-18

Fruit were harvested in the same way as for Fox Rd, but at 8:30 AM and 2 PM on 22 November. Typical fruit surface temperatures were about 29 and 37°C, respectively.

Desapping and abrasion

The fruit were desapped within 1 hour of harvest using a rack with a channel to collect the sap from the 20 fruit per harvest time per replication (Plate 1). The sap was frozen then transported to the laboratory in Brisbane with dry ice and stored at -18°C until analysed.

Sap was also collected in the same way from additional fruit harvested at 6 AM and 2 PM for testing sap effects on fruit (see below).



Plate 1 The desapping rack used to collect sap from the 20 fruit per replication. Ten fruit were desapped at one time.

After desapping all the fruit for each harvest time were immediately abraded using the standard USB abrasion test. This consisted of abrading the fruit for 2 seconds at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito) at a speed setting of five (on a scale of 1-6), using 80 grit sandpaper, and with about 110 g of pressure at the sanding disc (Plate 2). The sanding disc was scrapped clean after every 3-5 fruit to ensure the sandpaper did not clog with fruit skin.



Plate 2 Applying the USB abrasion test with a small orbital finishing sander.

After desapping and abrasion, half the fruit per replication (10 fruit) were placed in a 12°C coldroom at the Katherine Research Station within 2 hours of harvest, and the remainder were left at ambient temperature (typically about 30°C) for 24 hours from harvest, then placed at 12°C. After about 2 days the fruit were transferred to the packhouse coldroom at Seven Fields (Katherine) set at 10°C for a further ~5 days, then transported to Wamuran (south east Queensland) on the same transport as the commercial trial fruit (see below). Fruit were then transported to the Eco-Science Precinct (Department of Agriculture and Fisheries, Brisbane), ripened at 20°C and assessed for USB when ripe.

Sap effects

To test if sap characteristics contribute to USB diurnal effects, the sap was collected from 3-4 trays of 'Honey Gold' fruit harvested at either 6 AM or 2 PM. The sap collection was done as either the spirt sap released in the first 20-30 seconds after stem removal, or ooze sap released in the following 2 minutes. Within several hours of collection, 0.1 mL of either the spirt or ooze sap, or of the combined sap, was placed on 1 cm² filter paper then the filter paper placed over a small, lightly abraded area, on two locations on the fruit. This area was covered with aluminium foil (Plate 3), and the fruit were placed at about 13°C for ~6 days, then road-freighted to Brisbane under commercial conditions and ripened at 20°C before assessing for damaged areas around the abrasion sites.

To test the effects of the main ingredients of the oil fraction in the sap, 0.1 mL of pure and 3X diluted terpinolene, pure and 10X diluted carene, pure and 10X diluted D-limonene and distilled water were placed on 1 cm² filter papers as above, stored, transported, ripened and assessed.



Plate 3 Sap and oil fraction components placed on filter paper over small abraded sites on the fruit, then covered with aluminium.

Commercial trial

Commercially grown 'Honey Gold' fruit in blocks 8-11 at Fox Rd were harvested under typical commercial conditions over 24 hours, from midnight on the 19th to midnight on the 20th November. The fruit were harvested with a standard Horton mango harvest aid, with each of three picking crews working from midnight-10 AM, 10 AM-6 PM, and 6 PM-midnight. The crews were supervised to encourage standard picking practices. The harvest started in about row 1 of the block and progressed sequentially down the rows. Approximately 90, half ton bins were harvested over the 24 hours. The bins picked just before the hour and just after the hour were labelled to provide two sample bins on each hour. The bins were transported to the holding shed on farm within 1 hour of harvest and held in the shade before transporting to the packhouse. The delay between harvesting and transporting to the packhouse was not consistent for all harvest times because of logistical constraints. The bins were held at the packhouse at ambient temperature in the shade until packed.

The 24 harvest times were packed at the Seven Fields packhouse in Katherine during late morning of 21st of November. The packhouse procedures included a water dump, cold Sportak spray, brushing, sorting and weight grading. Several marked fruit were placed on the pack line at the start of loading the two bins for each hour onto the pack line. At the packing station, eight trays of premium count 14 fruit were selected per harvest hour and placed on a pallet. After packing all treatments, the fruit were held in a non-refrigerated holding area of the packhouse. The fruit were transferred to the pack house cold room set at ~10°C at different intervals after packing to ensure a fairly consistent delay between picking and cooling of about 1.5 days for all harvest times. Attempts were made to ensure consistent exposure to the cold air

in the cold room by trying to hold the trays for each harvest time on top of other pallets (that is, no covering over the trays) for a similar period, because previous trials indicated that more rapid cooling can increase USB. However, this was not always possible because of limited cold room space.

The delay between harvesting and packing was inconsistent because all fruit had to be packed at the same time to minimise disruptions to the packhouse. However, the delay between harvest and placing at 10°C was relatively consistent for each harvest time, at about 35-36 hours.

Once all treatments had been transferred to ~10°C and held there for at least 12 hours, all trays were unloaded from the pallets and evenly re-allocated across two new pallets. One tray from each of the first eight harvest times were placed on the first row of the first pallet, and a tray from the next eight harvest times placed on the first row of the second pallet. A tray from each of the remaining eight harvest times was then placed on the second row of the first pallet. Then a second tray from the first eight harvest times was placed on the second row of the second pallet, and so on. In this way, the eight trays from each harvest time were evenly distributed across the two pallets and within each row of each pallet. The eight trays from each harvest time (total of 192 trays) occupied the bottom 12 layers of each of the two pallets, with the remaining four layers filled with standard commercial fruit. Typically, the top 3-4 layers often suffer the greatest transport damage because of bouncing, so these rows were not occupied by the trial fruit.

Several probes attached to temperature loggers (Hobo model U12-14 data logger fitted with a T type thermocouple) were inserted into fruit at least three rows from the top of the pallet to track cold room and transport temperatures.

The pallets were held in the packhouse cold room (set at 12°C) for a further ~6 days. They were then placed over the rear axle of a standard 20 pallet (40 foot) refrigerated trailer, set at about 14°C. The side of the pallet that would be facing the left-hand edge of the road was marked to confirm whether the fruit on the side of the pallet away from the centre of the road develops more USB because of the camber of the road from the centre to the outside.

On arrival at Wamuran (near Caboolture, South East Queensland) the fruit were treated with about 10 ppm ethylene at 18°C for 2 days, then ripened at 18°C. All treatments were assessed for USB when most of the fruit had reached colour stage 6 (90-100% yellow colour). The location of each tray in the pallet, and the location of each fruit in the tray with USB was recorded.

USB assessment

The number of abrasion points or sap/constituent application points on each fruit that developed USB or skin damage was recorded. The length (L) and breadth (B) of the abrasion area alone, and of the abrasion + USB lesion were measured. The area was calculated as $Area=L*B$. The area of USB alone was calculated by subtracting the area of the abrasion from the total area of abrasion + USB.

Where appropriate, this area was converted to a rating scale as used in previous years, based on:

- 0 = nil
- 1 = less than 1 cm² of skin affected
- 2 = 1-3 cm² (approximately 3%, area of five cent coin)
- 3 = 3-12 cm² (approx. 10% of total fruit area)
- 4 = 12 cm² (approx. 10%) to 25%
- 5 = >25% of the skin effect of the skin affected

The area and severity of USB lesions not associated with abrasion treatment (in other words, developed on other areas of the fruit) were also recorded.

The incidence of USB within each replication was calculated as the percentage of fruit or abrasion sites that developed USB relative to the total number of fruit or abrasion sites. The commercially significant incidence was assessed as the percentage of fruit with more than 1 cm² of USB. This is the severity above which fruit are downgraded from premium to first grade.

Statistical analysis

For the R&D trial there were 10 trees per replication, with one fruit per tree per treatment, and four replications (rows) per harvest. Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), with the 'General Analysis of Variance' model used to analyse the data. In all

trials, the least significant difference (LSD) procedure at $P = 0.05$ was used to test for differences between treatment means.

The commercial trial was designed as a preliminary trial and was not statistically replicated because of lack of on-farm resources and the short harvest time.

Results and discussion

R&D trial

Fruit temperatures at harvest

Fruit surface temperatures increased from 20°C at 6 AM to almost 45°C at 10 AM, then decreased to about 27°C by 10 PM (Figure 1).

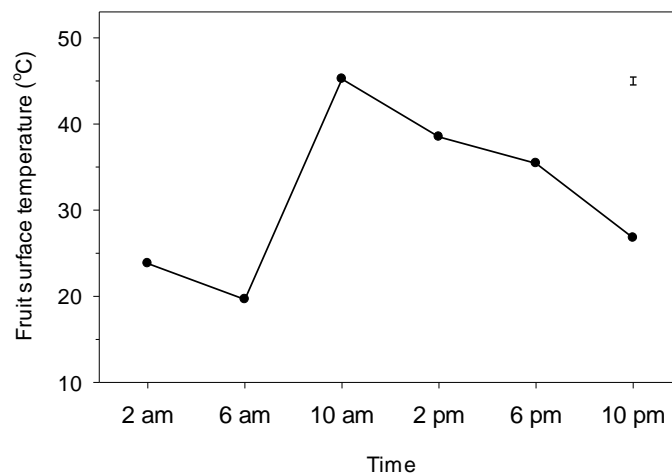


Figure 1. Surface temperature of 'Honey Gold' mango fruit used in the diurnal R&D trial.

Fruit temperatures after harvest

Fruit pulp temperatures decreased slowly to 14°C over about 4 days, then remained unchanged for a further 6 days before road freight to south east Queensland (Figure 2). The fruit were ripened for several days at Wamuran at about 22°C, and were then transferred to a cold room at the Eco-Sciences Precinct.

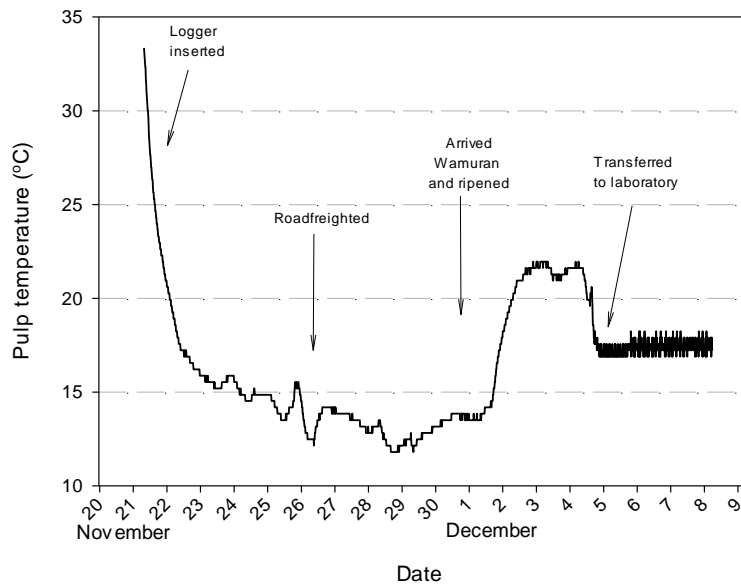


Figure 2 Recorded pulp temperatures of trial fruit.

Under skin browning

Typical USB symptoms were observed around the abrasion sites (Plate 4). The % of fruit with USB of more than 1 cm² was the lowest in fruit harvested from 10 PM to 6 AM and the highest in fruit harvested between 2-6 PM (Figure 3). There was no difference in incidence between fruit placed in the cold room immediately after abrasion or held for 24 hours before cooling. Similar patterns were observed for the percentage of abraded sites with USB, but only in those fruit placed in the cold room immediately after abrasion. There was little diurnal effect if fruit were placed in the cold room 24 hours after abrasion. The average severity of affected fruit was not influenced by harvest time as much as was incidence.

These results are similar to those observed in previous years. They suggest that the percentage of fruit with commercially significant USB is considerably reduced when fruit are harvested at night, and are not influenced by delays in cooling. This effect is largely a result of more abrasion sites developing USB, particularly when the fruit were placed in the cold room fairly quickly after abrasion. Harvest time had a relatively small effect of the severity (area) of the USB around the abrasion site.

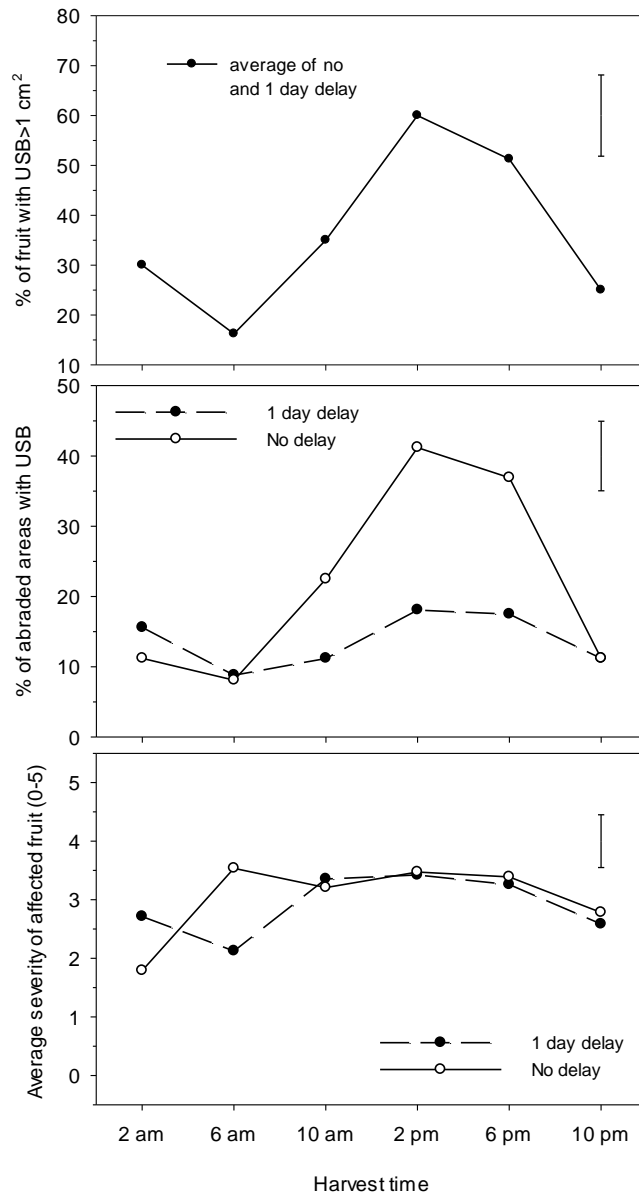


Figure 3 Under skin browning (USB) associated with the abrasion test. The percentage of 'Honey Gold' mango fruit with USB lesions of more than 1 cm², the percentage of the abraded areas that developed USB, and the average USB severity of the affected fruit, when harvested at different times during the day and night from the Fox Rd farm. All fruit were abraded within 1 hour of harvest, however some fruit were placed in the coldroom after one day ("1 day delay") and others were placed in the cold room within 2 hours of abrasion ("no delay"). The first graph represents the average harvest time effects across both "no delay" and "1 day delay" because the effects of harvest time were similar for both "delay" treatments. If the difference between means is less than the vertical bar in each graph, then there is no statistically significant difference between those means (P=0.05).

USB lesions were also observed on areas of the skin that had not been abraded, presumably largely facilitated by physical damage caused during handling and particularly transport. This would likely reflect typical USB occurring under commercial conditions. The results indicated that the incidence of fruit with commercially significant USB not caused by the USB test was also lower in fruit harvested from 10 PM-6 AM. Delaying for 24 hours before cooling increased the incidence in fruit harvest at 10 AM, but there was little statistical difference between no delay and a 24 hour delay with fruit harvested at other times. Hence these results generally reflect those using the USB test.



Plate 4 Typical USB on fruit harvested at 10 AM (left) and at 10 PM (right). The fruit were abraded and placed at 12-14°C immediately after abrasion, held at these temperatures for about 6 days, then road freighted to Brisbane and ripened at 20°C.

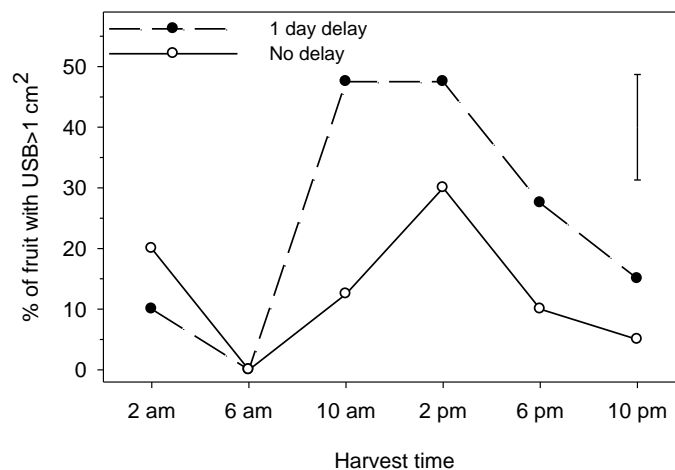


Figure 4 Under skin browning (USB) not associated with the abrasion test: The percentage of 'Honey Gold' mango fruit with USB lesions of more than 1 cm², when harvested at different times during the day and night from the Fox Rd farm. All fruit were abraded within 1 hour of harvest, however some fruit were placed in the coldroom after one day ("1 day delay") and others were placed in the cold room within 2 hours of abrasion ("no delay"). If the difference between means is less than the vertical bar, then there is no statistically significant difference between those means (P=0.05).

In a small separate trial with Fox Rd fruit harvested at 6 PM, 1 day delay between abrasion and cooling again reduced the average area of USB around abrasion sites that developed USB (Table 1). Delaying abrasion and cooling also reduced the average area. This confirms the benefits of delaying cooling, irrespective of the abrasion time.

With fruit from Gorge Rd, afternoon-harvested fruit cooled immediately after abrasion had a significantly greater percentage of the abraded sites with USB compared with fruit harvested in the morning (Table 2). A 1 day delay between abrasion and cooling significantly reduced the percentage of abraded sites with USB, and under these conditions there was no effect of harvest time. These effects are similar to those from Fox Rd.

Table 1 'Honey Gold' fruit harvested from Fox Rd at 6 PM as a separate trial, and after the standard abrasion test. Fruit were either abraded immediately after harvest and placed in the cold room within one hour of abrasion, or abraded soon after harvest then placed in the cold room after one day, or abraded then placed on the cold room 24 hours after harvest. Means with the same letter within the same column are not statistically different (P=0.05).

Treatment		% abraded areas with USB	The average area of USB around affected abrasion sites (cm ²)
When abraded	When cooled		
Within 1 hour	Within 1 hour	37 ^{ab}	26 ^b
Within 1 hour	After 24 hours	18 ^a	15 ^a
After 24 hours	After 24 hours	49 ^b	14 ^a

Table 2 Percentage of abraded areas that developed USB when harvested at different times during the day in 'Honey Gold' fruit harvested from Gorge Rd and subjected to a standard abrasion test. All fruit were abraded within 1 hour of harvest, however some fruit were placed in the coldroom after one day ("1 day delay") and others were placed in the cold room within 2 hours of abrasion ("no delay"). Means with the same letter are not statistically different (P=0.05).

Harvest time	% of abraded areas with USB	
	No delay	1 day delay
8.30 AM	9 ^a	14 ^{ab}
2 PM	28 ^b	11 ^a

Sap effects

Placing 0.1 mL sap onto fruit often resulted in significant brown-coloured damage to the surrounding skin. The symptoms were similar but not identical to USB (Plate 1), but illustrated the potential for sap to cause significant damage.

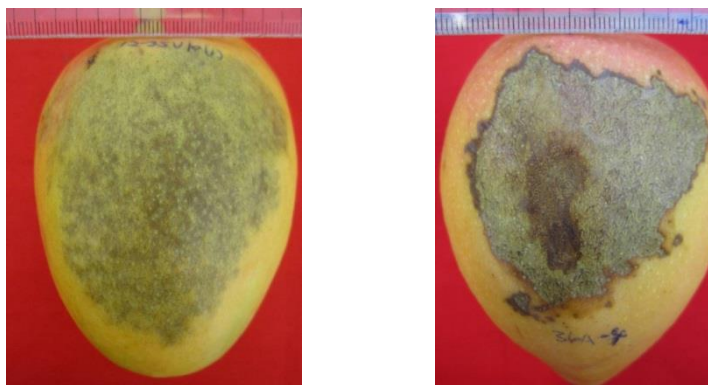


Plate 5 Typical under skin browning (left) and the USB-like symptoms (right) when sap from the diurnal 'Honey Gold' fruit were placed onto small abraded areas of the skin.

Neither water, nor the ooze sap obtained from morning or afternoon-harvested fruit resulted in damage when placed on the fruit (

Table 3). The spirt sap from morning-harvested fruit also resulted in no damage. However the whole sap and the spirt sap from afternoon-harvested fruit resulted in significant damage to the fruit. In addition, the afternoon spirt sap resulted in a higher percentage of the treated sites developing skin damage to fruit harvested in the afternoon compared to morning-harvested fruit.

These results suggest that two factors are involved in the higher sensitivity of afternoon-harvested fruit to USB; more sensitive skin on the afternoon-harvested fruit, and components of the afternoon sap have greater potential to cause skin damage. These components are associated with the spirt sap.

Table 3 The potential contribution of mango sap to the development of USB on 'Honey Gold' fruit. Sap was collected from morning and afternoon-harvested fruit. Where appropriate, the spirit sap and the ooze sap were separated. A sample of 0.1 mL of the whole sap, or the oil or water fraction was placed on 'Honey Gold' fruit harvested either in the morning or the afternoon, the area covered with aluminium foil for several days, then the fruit allowed to ripen. Skin damage was assessed as the percentage of fruit showing damage greater than 1 cm², or the percentage of treated sites with damage, or the severity of the affected area using a rating scale of 0-5. Means in the same column with the same letter are not statistically different (P=0.05).

Treatment	% fruit with damage >1cm ²	% treated sites with damage	Severity of affected fruit (0-5)
Water	0 ^a	0 ^a	0 ^a
Applied to morning-harvested fruit			
Afternoon sap	86 ^c	50 ^b	2.7 ^c
Afternoon ooze sap	0 ^a	0 ^a	0 ^a
Applied to the afternoon-harvested fruit			
Morning spirit sap	0 ^a	7 ^a	0.1 ^a
Morning ooze sap	0 ^a	0 ^a	0 ^a
Afternoon sap	100 ^c	100 ^c	2.2 ^b
Afternoon spirit sap	100 ^c	100 ^c	2.9 ^c
Afternoon ooze sap	0 ^a	0 ^a	0 ^a

Carene resulted in no skin damage, while both D-limonene and terpinolene resulted in damage to all the fruit (Table 4). There was no evidence of differing efficacy between these two components.

Table 4 Damage to the skin of 'Honey Gold' mango fruit at the ripe stage following application of 0.1 mL of either water, or three of the main components of the oil fraction in the mango sap to the fruit. The compounds were placed onto the fruit within 2 hours of harvest. The area was covered with aluminium foil for several days, then the fruit allowed to ripen. Skin damage was assessed as the percentage of fruit showing damage greater than 1 cm², or the percentage of treated sites with damage, or the severity of the affected area using a rating scale of 0-5. Means in the same column with the same letter are not statistically different (P=0.05).

Treatment	% fruit with damage >1cm ²	% treated sites with damage	Severity of affected fruit (0-5)
Distilled water	0 ^a	0 ^a	0 ^a
Carene	0 ^a	7 ^{ab}	0.1 ^{ab}
Carene diluted 10X	0 ^a	0 ^a	0 ^a
D-limonene	100 ^b	100 ^c	4 ^c
D-limonene diluted 10X	0 ^a	0 ^a	0 ^a
Terpinolene	100 ^b	100 ^c	4 ^c
Terpinolene diluted 3X	7 ^a	14 ^b	0.3 ^b

Commercial trial

The two pallets containing trial fruit were placed over the rear axle of the truck to maximise the potential for vibration damage. Significant movement of the trays during transport from the Northern Territory to south east Queensland was observed (Plate 6). This compromised pallet integrity, damaged the trays and most likely increased USB. USB was commonly observed, and was mostly on the stem end of the fruit, or on the sides of the fruit in contact with other fruit or the sides of the tray.



Plate 6 Damage to pallets placed over the rear axle during road freight from Katherine to south east Queensland, and USB observed in the trays from the commercial trial. Most of the damage was on the stem end of the fruit, and on the contact points with other fruit or the tray.

The commercial trial aimed at identifying the effects of diurnal harvesting on commercially picked, packed and transported fruit, but no consistent treatment effects occurred (Figure 5). Considerable statistical compromises were made in this trial because of commercial constraints associated with the diurnal commercial pick, short harvest window requiring “all hands on deck”, constraints on logistics between farm and packhouse and high packhouse workloads. These included:

- The lack of replication of picking teams. Picking teams can have a significant effect on harvest damage. Ideally the same picking team should have harvested over 24 hours, or more harvest aids and teams used to overcome the harvest team effect.
- Fruit were harvested from the same blocks because of logistical difficulties in moving the slow harvest aids from one block to another every hour.

- There was variable time between harvesting and packing because of the need to minimise disruption in the packhouse.
- Tray location in the pallet, and pallet location in the truck are likely contributors to physical transport damage, and therefore resulting in USB expression. However, statistical analysis did not reveal a significant effect of layer on the pallet on USB incidence or severity.

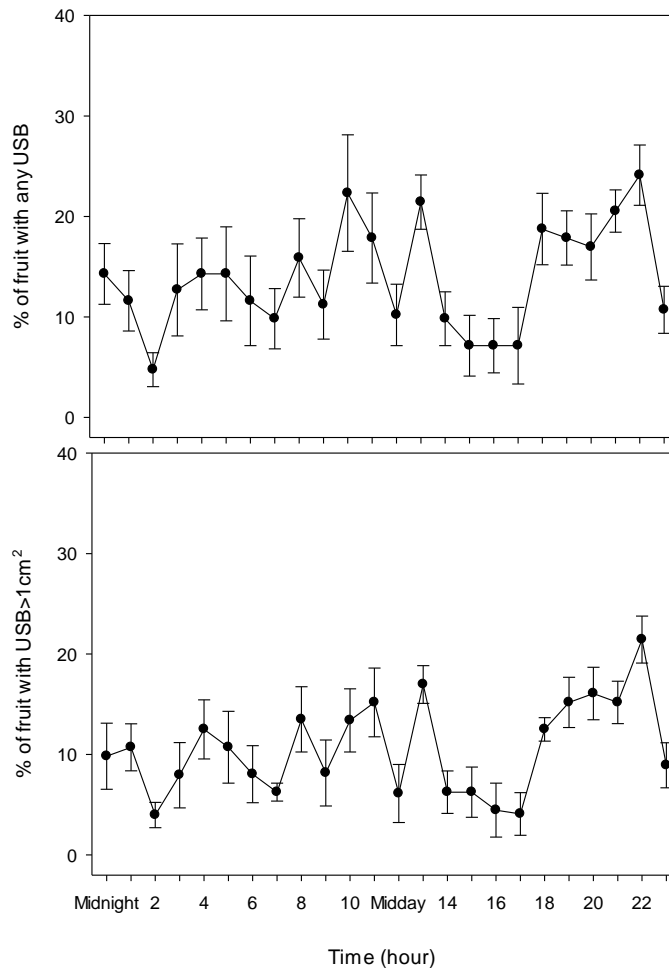


Figure 5 Under skin browning (USB) on 'Honey Gold' mango fruit at ripe. Samples of commercially harvested fruit were collected every hour, commercially picked and packed then placed at 12-14°C within 36 hours of harvest. The fruit were then held for about five days before road freight transport to south-east Queensland and ripening. USB was assessed as the percentage of fruit showing any USB, and the percentage of fruit with USB greater than 1 cm². The vertical bars represent the standard error of the mean (n = 8).

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Comparing USB susceptibility in various mango cultivars

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Pip Bryant, Gavin Scurr
(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to underskin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest, subsequent low temperature storage and vibration damage in transport.

Commercial observations suggest that of the main Australian cultivars, 'Honey Gold' is the most susceptible to USB. 'Honey Gold' has also been the principal subject of most previous research into USB.

An exploratory trial was carried out to compare USB susceptibility in a selection of mango cultivars grown in Australia; 'Kensington Pride', 'R2E2', 'Calypso', 'Honey Gold', and 'Lady Jane'. The fruit were harvested from commercial farms in the Katherine region of the Northern Territory, and were treated by a standard abrasion and cool storage regime developed to induce USB.

'Honey Gold' fruit showed the highest overall susceptibility to USB of the 5 cultivars tested. 'Lady Jane' showed similarly high incidence of USB, with symptoms that were much smaller in size, but observed to be more intense in colour. 'R2E2' showed a commercially significant incidence of USB, with more than one third of fruit affected. Low levels of mild USB were shown to occur in 'Kensington Pride', while 'Calypso' fruit showed no signs of the disorder.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

'Honey Gold' mango appears to be the most sensitive to USB of the main Australian cultivars, and has been the principle subject of USB research to date. It has not been established whether other cultivars may also be susceptible to the disorder. Testing USB susceptibility in other cultivars will identify whether similar control measures recommended for 'Honey Gold' will have application more widely.

Materials and Methods

Fruit

Fruit from 5 mango cultivars were obtained from commercial orchards located in Katherine, Northern Territory (NT) (Table 1). All fruit were similarly harvested at midday to early afternoon, with 2 trays of fruit (totalling 24-42 fruit per cultivar) harvested for each cultivar.

Table 1: Cultivars harvested, farm locations in Katherine, Northern Territory (NT) and the time and date of harvest.

Cultivar	Farm	Time of harvest	Date of harvest
'Honey Gold'	Piñata, Fox Road	12 pm	19 th Nov 2015
'Lady Jane'	7 Fields, Fox Road	2 pm	18 th Nov 2015
'R2E2'	Dalgliesh, Fox Road	2 pm	18 th Nov 2015
'Kensington Pride'	Dalgliesh, Fox Road	2 pm	18 th Nov 2015
'Calypso'	Nucifora, Quarry Road	2 pm	19 th Nov 2015

USB abrasion test

The fruit were abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial 12°C-set cold room for at least six days, then placed on a pallet near the rear of a refrigerated road trailer, and transported to Wamuran, South East Queensland (SEQ) at a set temperature of 14°C. The fruit were transported by car to Maroochy research Facility (MRF), Nambour (SEQ) for assessment.

The fruit were ripened at 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly recorded.

Analysis

Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), using the 'General Analysis of Variance' model, with individual fruit as experimental units. The least significant difference (LSD) procedure at P=0.05 was used to test for differences between treatment means.

Results and discussion

Under skin browning

Under skin browning was observed in all cultivars except 'Calypso' (Table 2). 'Honey Gold' showed the highest USB rating, and largest area of the 5 cultivars tested, confirming the acute susceptibility of this cultivar. The 'Lady Jane' cultivar showed a similar high incidence of USB as 'Honey Gold', but the USB area was much smaller in size. USB symptoms in 'Lady Jane' fruit were observed to be typically of a dark, purplish colour with a discrete edge (Plate 1). In contrast, 'R2E2' tended to show lighter, more diffuse areas of discolouration. More than one third of 'R2E2' fruit showed signs of USB, suggesting that the disorder could also be commercially significant in this cultivar. 'Kensington Pride' fruit showed low levels of USB incidence, of very small size, while 'Calypso' did not show any USB.

Table 2: USB incidence and severity in various mango cultivars grown in Katherine, Northern Territory.

Cultivar	DM (%)	Incidence of any USB > 1cm ² (%)	Average USB rating (0-5) (incl. abrasion and background USB)	Total USB area per fruit where USB occurred (cm ²)
'Honey Gold'	19.4 ^a	81.0 ^a	3.4 ^a	40.6 ^a
'Lady Jane'	16.5 ^c	71.9 ^a	2.5 ^b	9.2 ^b
'R2E2'	16.3 ^c	37.5 ^b	1.4 ^c	18.1 ^b
'Kensington Pride'	17.1 ^{bc}	10.3 ^c	0.4 ^d	4.5 ^b
'Calypso'	17.9 ^b	0.0	0.0	0.0
Average LSD	0.85	21.04	0.80	22.41
Sample size	2	24-42	24-42	6-35

Data analysed by ANOVA. Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Plate 1: USB symptoms in 'R2E2' and 'Lady Jane' cultivars – 'R2E2' tended to show larger areas of USB of lighter colour, while 'Lady Jane' showed smaller darker USB discolouration.



Tray inserts and USB

Improving consumer appeal of 'Honey Gold' (MG13016)

Guoqin Li, Daryl Joyce, Peter Hofman, Andrew Macnish,
Roberto Marques

(2013/14)



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Summary

Under skin browning (USB) reduces the visual appeal of 'Honey Gold' mango, and other cultivars to a lesser extent. Previous research has identified a combination of low temperatures and physical damage to the fruit increases the susceptibility to USB, and that USB is often worse after road transport. This trial tested the effects of two tray inserts on USB; the standard plastic insert and a softer, expanded polystyrene insert, but with less form and depth. Transport was simulated by placing the fruit in the trays onto a vibration table delivering 15 Hz for 3 or 9 h. The results indicated that the softer insert can reduce USB after vibration and cold storage at 13°C of 8 d. Observations from commercial shipments from the NT to Brisbane testing the different inserts suggested that the softer inserts reduced USB on the bottom of the fruit in contact with the insert, but the lower form did not hold the fruit well so there was more USB at the contact points with the walls of the tray and with other fruit. Further work is required to find a soft insert with deep form that will hold the fruit in position better and reduce rubbing with the tray wall, and with other fruit.

Introduction

Under-skin browning (USB) lessens the visual appeal of 'Honey Gold' mango, and other cultivars to a lesser extent. Previous research has identified a combination of low temperatures and physical damage to the fruit increases the susceptibility to USB.

Under skin browning is often worse following road transport from the NT to southern states (Marques *et al.*, 2012). In these circumstances, USB is often associated with obvious physical damage to the fruit from rubbing against the plastic tray inserts or the tray itself, USB can be reduced by placing plastic around the fruit to prevent direct contact with the insert, liner and adjacent fruit (Marques *et al.*, 2012). Preliminary observations also suggest that using a softer inserts from expanded polystyrene may also reduce USB.

This trial assessed the impact of two tray inserts on USB. 'Honey Gold' mango fruit were placed on the two tray insert designs inside cardboard cartons and placed on the vibration table to simulate roadfreight. The fruit were held at 12°C for 4-6 days to facilitate USB development, and then assessed at the near ripe stage.

Materials and methods

Fruit

'Honey Gold' mango fruit were obtained from three regions: Northern Territory, north Queensland and south east Queensland. Fifteen fruits (replications) per treatment were used. All fruit were commercially picked and packed. Those from the NT and north Queensland were airfreighted to Brisbane, and then transported by air-conditioned car to the University of Queensland postharvest laboratories at Gatton campus. Fruit from south east Queensland were collected at the end of the packing line and transported by car to Gatton within one day of harvest.

Treatments

The treatments were:

- Insert type: standard plastic insert or softer expanded polystyrene liner but with less form or ability to hold the fruit in place during transport.
- Vibration duration: either 3 or 9 h.

All fruit were randomly assigned to trays (one tray per treatment), each with one of the two different inserts. The trays were fastened to the 1 m² base of the vibration table using brackets over each tray, screwed to the table. The vibration table was set to deliver 15 Hz as measured by slow speed video camera. The treatments remained on the vibration table for either 3 or 9 h. The fruit were equilibrated to 12°C overnight before treatment, and the vibration table and the treatments held in a 12°C coldroom throughout. Following vibration, fruit remained at 12°C for a total of 8 d then ripened at 20°C. Controls were held under the same temperature conditions as above, but not vibrated.

Assessment

Under-skin browning (USB) severity was assessed using the following rating scale:

- 0 = Nil
- 1 = less than 1 cm²
- 2 = 1-3 cm² (approx. 3% of total fruit surface area, 5 cent coin)

- 3 = 3-12 cm² (approx. 10%)
- 4 = 12 cm² (approx.10%) to 25%
- 5 = more than 25% of the skin area affected.

USB-affected areas were photographed with a Canon D40 digital camera, and the USB area estimated using ImageJ (shareware software). The incidence of USB was expressed as the proportion (%) of fruit in each replication with USB.

Statistical analysis

Fifteen, single fruit replications were used. For incidence the data for fruit without USB was converted to 0 and fruit with USB converted to 1. The GenStat (Version 14) general linear model with binomial analysis and an unbalanced design was then used. Significant differences between treatment means were determined using the least significant difference (LSD) at P=0.05.

Results and discussion

Laboratory trials

Nine hours vibration significantly increased the USB incidence in fruit from the NT farm (Table 1). The soft insert resulted in less USB on fruit from the NQ farm following 9 h vibration, compared to the plastic insert. There were no significant effects on USB severity or area affected (data not shown). Plate 1 illustrates the effect of vibration and insert on USB.

No significant difference was found on USB severity or area.

Table 1 Effect of duration of vibration (15Hz) on the incidence (percentage of fruit affected) of under skin browning on 'Honey Gold' mango fruit. The trays had either a plastic insert, or a softer, expanded polystyrene insert. The vibration treatment was conducted at 12°C, and the fruit held for a total of 8 d at 12°C before ripening (except control). The fruit were obtained from a farm in Katherine (Northern Territory) and Mutchilba (north Queensland) (2012/13). Means in the same column with the same letter are not significantly different at P =0.05.

Treatment	Incidence (% of fruit with USB)	
	NT farm	NQ farm
20°C, no vibration (control)	0 ^c	0 ^b
12°C, no vibration	0 ^c	7 ^b
12°C, 3 h vibration, plastic insert	7 ^{bc}	13 ^b
12°C, 3 h vibration, soft insert	20 ^{bc}	7 ^b
12°C, 9 h vibration, plastic insert	60 ^a	53 ^a
12°C, 15Hz, 9 h vibration, soft insert	33 ^{ab}	0 ^b



Plate 1 NT farm: 'Honey Gold' mango fruit following nine hours vibration at 15 Hz, with either the standard plastic insert (left) or these softer expanded polystyrene insert (right).

Commercial observations

The softer, polystyrene insert has been used in semi-commercial trials over the last two seasons. Outturn assessments revealed that:

- There was generally less USB with the softer liner
- With the plastic insert, USB was mainly on the base of the fruit which is in direct contact with the more rigid insert.
- The polystyrene liner resulted in less USB on the base of the fruit in contact with the insert. However, the liner has less form and rigidity, so there was often more movement of the fruit during transport (Plate 2). Hence fruit transported in this softer insert generally had less USB lesions, but they were usually larger in area and occurring mainly on the sides of the fruit in contact with another fruit and the tray (Plate 3).



Plate 2 Commercial consignment of 'Honey Gold' mango fruit transported from the Northern Territory to south-east Queensland in a 20 pallet trailer. Tightly packed fruit are held in position well (left), but less tight packs (right) allow considerable fruit movement due to truck vibration. The soft, polystyrene liner has minimal form or ability to hold fruit in position and prevent fruit-fruit and fruit-tray contact.



Plate 3 The under skin browning on the parts of the fruit in contact with the sides of the tray and other fruit, often observed when the softer insert was used. The insert reduced USB on the base of the fruit because of the softer insert material, but the low form of the insert allowed more rubbing against the sides of the tray and other fruit.

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Comparison of two liner types on the development of USB and physical damage in ‘Honey Gold’ mango

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Hung van Duong, Peter Hofman, Pip Bryant, Ted Winston,
Gavin Scurr

(2015/16)

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. The development of the disorder is associated with the combination of hot growing and harvest conditions, physical injury to the fruit, and low storage temperatures. Previous research indicated that bubble wrap and thin plastic between the fruit and the tray insert and the side of the tray can reduce USB in commercial consignments, suggesting that improved tray inserts or liners may provide similar benefit.

In this trial a new suspension style tray liner was tested against the standard industry tray liner to assess the potential for reducing physical damage and USB. 'Honey Gold' mango fruit were commercially packed into these liners, cooled to about 16°C then road-freighted in a commercial refrigerated trailer from Katherine (Northern Territory) to Wamuran (50 km north of Brisbane). The fruit were ripened then assessed for USB and signs of vibration damage.

There was no strong evidence that the suspension tray liner reduced physical damage or USB in 'Honey Gold' mango. Further customisation of the tray liner to suit fruit shape and tray size may be required to prove the benefits of this liner design.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results have consistently shown an association between physical damage to fruit and the development of USB symptoms. Under commercial operations physical injury resulting in USB typically occurs through vibration damage during road transport. Rubbing of the fruit against tray liners, other fruit or tray edges are the primary causes of physical injury during transport, and USB commonly develops around these injury sites (Marques et al., 2011). The protection of fruit against vibration damage in transit has shown potential to reduce USB, with bubble wrap around fruit reducing USB incidence from 50% to 8% (Marques et al., 2012). While this degree of protective packaging would not be economically feasible, the results demonstrate the advantage of exploring options for more protective tray liners.

The typical tray liner used by the mango industry is of thin but relatively rigid polyethylene plastic with "cups" to provide the packing pattern. The edges of the cup can cause physical damage in some designs, and the base of the cup often becomes crinkled, which can also cause damage to the skin. Softer liners from expanded polystyrene have been tested on 'Honey Gold' mangoes. Observations of commercial shipments indicate a reduction of USB on the base of the fruit, but with USB now concentrated around the contact points with other fruit and the side of the tray (Plate 1). It was hypothesized that the soft liners reduced the damage caused by fruit rubbing against the ridge of the liner cup, but that the low profile resulted in more damage against the sides of the tray and other fruit.



Plate 1 Typical under skin browning (USB) on 'Honey Gold' mango fruit (left), which often occurs at the contact points with other fruit, or with the side of the tray (right).

A new liner by Multitray (the Netherlands) has a suspension style design, with malleable cups that invert to cradle the fruit. Suspension tray liners have shown benefits in reducing physical damage to fruit during transport (Thompson et al., 2008). This exploratory trial assessed the suitability of the Multitray suspended tray liner to reduce USB compared with the expanded polystyrene liner used for 'Honey Gold' from the NT.

Materials and Methods

Treatments

This exploratory trial was conducted on 'Honey Gold' mango fruit harvested commercially at Fox Rd, Katherine (Northern Territory) in late November 2015. The treatments were the standard expanded polystyrene liner used for 'Honey Gold' grown in the NT, and the Multitray suspension liner, with cups that are inverted to mould around the fruit. The average 'Honey Gold' size is 14 fruit per tray 6.5 kg tray (count 14), however the trial was conducted with the smaller count 18 fruit to suit the count 18 suspension liner provided.

Following commercial harvest and grading, the fruit were packed into a total of 21 trays using each liner treatment. The trays were packed into layers 4 to 9 (from the top) of a single pallet, with 2 trays of each treatment in each pallet layer (excluding pallet layer 4, which contained 1 tray of each). The location of trays within the pallet layer was varied on each level to ensure that the two treatments were evenly allocated across the 8 vertical columns of trays. Non-treated fruit trays were packed around the experimental fruit for the remainder of the pallet.

Fruit were stored on-farm at about 14°C for at least 4 days to maximize the potential for USB expression, and were then transported by commercial, 20 pallet refrigerated trailer (16°C set temperature) by road to Wamuran (about 50 km north of Brisbane). The pallet was located over the rear axle of the trailer to maximize vibration damage. At Wamuran, the fruit were ripened according to normal commercial practice, which included several days of ethylene at about 20°C. The fruit were assessed close to eating ripe for USB and rub mark injury (from vibration during transport) using the following rating scale:

- 0=nil,
- 1=up to 1 cm²,
- 2=1 to 3cm²,
- 3=3 to 12cm² (10%),
- 4=>12cm² (10%) and <25%,
- 5=>25% of the fruit surface area affected.

In addition, the percentage of fruit in each tray that had rotated more than about 45° from their packed orientation (bottom of the fruit pointing up) was recorded (see Plate 4).

Statistical analysis

This trial was designed as an exploratory trial. The data are presented as means with standard error values.

Results and discussion

The suspension liner was slightly smaller than the inside dimensions of the tray. As a result, the liner slipped to the bottom of the tray when placed on an incline during packing (see Plate 2), so that the last row of fruit packed in the tray did not align neatly with the inverted cup. These fruit often were not placed neatly in the cups because of the misalignment of the cup with the remaining space in the tray (Plate 3), which could increase the risk of damage to the fruit due to contact with the sharper liner edges.

USB incidence was low in the trial (Table 1), with only 6% of fruit showing any commercially significant USB symptoms (greater than 1cm²). The incidence of rub mark from vibration during transit was too low for valid statistical comparison.

These preliminary results provide insufficient evidence of a liner effect on USB or rub marks, largely because of the low incidence.

The suspension liner held the fruit in position better than the current liner (Plate 4), with on average 14% of the fruit in the current liner out of position on arrival compared with less than 1% with the suspension liner. This should result in less rubbing with other fruit and with the tray walls, and potentially reduced USB on susceptible fruit.

Table 1. Under skin browning (USB) and vibration rub mark severity on 'Honey Gold' mango fruit packed with two different types of tray liners, and transported by truck from Katherine (Northern Territory) to Wamuran (south east Queensland) .

Liner Type	% of fruit with any USB		% of fruit with USB >1cm ²		Average USB severity on affected fruit (0-5)		Rub mark score (0-5)	
	mean	SE	mean	SE	mean	SE	mean	SE
Standard	9.5	1.5	4.8	1.5	1.7	0.1	0.04	0.01
Suspension	13.8	1.8	7.4	1.3	1.8	0.1	0.06	0.01

Data are presented as mean and standard error (SE) values (n=378 fruit).

Conclusions

These preliminary results with the suspension tray liner indicate the need for further refinement of the design. The cups could be tailored to better fit the shape of mango fruit, and the overall size of the liner increased slightly for a more snug fit into the mango tray. After these refinements, further testing would be warranted.

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Plate 2 The suspension liner in the tray. Note the 1 cm gap between the liner and the inside of the tray (left), which results in a gap at the top of the tray when inclined for packing (right).



Plate 3 The poor placement of the fruit in the last row to be packed (left). The cup edges are folded over and present sharper edges to the fruit that may increase vibration damage. The fruit removed from the tray on arrival in Wamuran (right) indicates that most of the fruit were well placed in the liner (right), except for the fruit packed last (top) in the tray.



Plate 4 Tray with suspension liner (left) and the currently used expanded polystyrene liner, on arrival at Wamuran. The fruit in the suspension liner showed less re-orientation than those in the standard liner.

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Tray liner effects on physical damage resulting from vibration simulation in 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Hung Van Duong, Andrew Macnish, Peter Hofman, Pip
Bryant

(2015/16)

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. The development of the disorder is associated with the combination of hot growing and harvest conditions, physical injury to the fruit during road freight, and low storage temperatures.

Tray liners can reduce physical damage by restricting fruit movement and providing cushioning. The current trial compared physical damage due to vibration in five different types of tray liners. The fruit were subjected to 3 hours of vibration on a vibration table to simulate the conditions of transport, and were later assessed for visible symptoms of physical damage.

The paper tray liner showed the lowest levels of physical damage, possibly due to deeper indentations cradling the fruit, and good cushioning properties. The standard industry tray and a deeper profile foam tray showed moderate levels of damage, while the newly developed suspension style tray and shallow foam tray showed the most damage.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Previous research has shown a strong link between physical damage and USB in 'Honey Gold' mangoes. The damage typically occurs during transportation by road freight from packing shed to distribution centres, over distances of 2000-3000 km. During transit, vibration is greatest directly over the truck axles, and vibration acceleration increases as it is transmitted through boxes or trays on a pallet (Thompson, 2007). Damage is usually most severe in fruit located in the uppermost boxes near the rear of a trailer (Fischer, 1989; Hinsch et al., 1993; Thompson, 2007). Previous studies have shown that the peak of vertical acceleration often occurs in the range of 2.5-9 Hz and 0.25-0.92 G and that vibration in this range typically inflicts the most damage to the produce (Berardinelli et al., 2005; Hinsch et al., 1993; Zhou et al., 2007). Vibration levels are dependent on the vehicle speed, road condition, packaging material and suspension type (Chonhenchob and Singh, 2003; Hinsch et al., 1993; Jarimopas et al., 2005).

Well-designed tray liners can reduce the physical damage resulting from vibration by providing cushioning and by restricting movement of the fruit. Protective packaging has shown the potential to substantially reduce USB, with the use of bubble wrap around fruit reducing USB incidence from 50% to 8% (Marques et al., 2012). While this level of protective packaging may be cost-prohibitive, the results demonstrate the benefits of exploring different packaging options.

The typical tray liner currently used in the mango industry is composed of thin, relatively rigid polyethylene plastic, with indented cups to hold each individual fruit in place. It has been previously observed that the hard cup edges, and crinkling in the base of the cup are potential sites of physical damage during transportation. Previous commercial trials comparing the standard liner with a shallow indented foam liner showed that the foam liner reduced damage to the base of the fruit, but resulted in more damage on the sides. This damage was thought to be due to increased rubbing against other fruit and the tray sides. It was proposed that a deeper profile foam liner may confer greater benefits by restricting the movement of the fruit. A recently developed liner by Multitray (the Netherlands) has a suspension style design, with malleable cups that invert to cradle the fruit. Suspension tray liners have shown benefits in reducing physical damage to fruit during transport (Thompson et al., 2008). The current study was carried out to test the effect of five different packing liners, including the industry standard, paper, shallow foam, deeper foam and suspension style, on the physical damage of mangoes using a vibration table to simulate the vibration generated during road transportation.

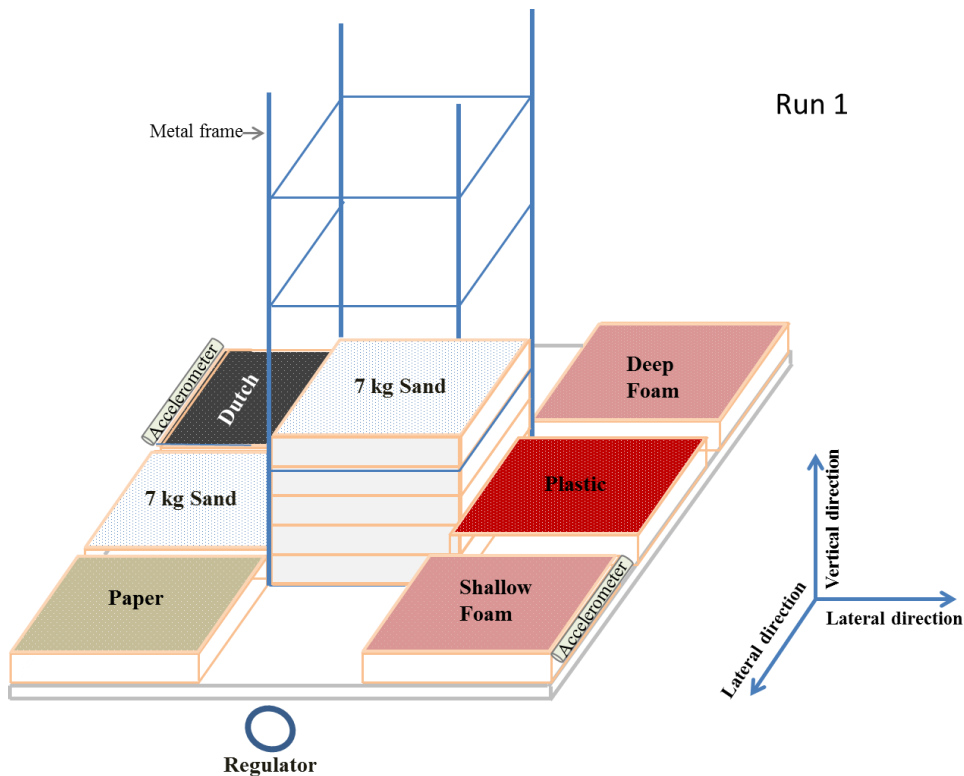
Materials and Methods

Treatments

Honey Gold mangoes were harvested from Piñata farm in Wamuran, South-East Queensland (SEQ) on Feb 17, 2016 and transported to the Piñata packaging shed for sorting. Fruit were then packed in trays of single layer fibre cardboard with a dimension of 43 cm length x 36 cm width x 13 cm height and carefully transported by car to the Maroochy Research Facility, Nambour, SEQ. Mangoes were stored at 20°C overnight prior to treatment.

Five types of liners, namely commercial plastic (size 14), paper type (size 18), Dutch suspension style tray liner (size 18), deep foam (size 14) and shallow foam (size 14) were tested. Mango trays were secured to the table using screws and plywood panels. The liners were tested in three runs, with liners arranged as shown in Figure 1. Six additional trays of 7 kg sand were placed on the table with the support of a metal frame to achieve the desired acceleration (approx. 0.5g) at a frequency of 9 Hz. Each run was operated for three hours under ambient environmental conditions. Fruit, after being subjected to vibration, were stored at 20°C for two weeks until obvious damage was visible. For each type of liner, 42 fruit were assessed for physical damage using following rating scale:

Rating scale	Damaged area (cm ² or % of fruit surface)
0	Nil
1	Less than 1 cm ² , 2 cm in length
2	1-3 cm ² (approx. 3%, or the size of a 5 cent coin), 5 cm in length
3	3-12 cm ² (approx. 10%, greater than 5 cm in length)
4	More than 12 cm ² (approx. 10% to 25%)
5	More than 25%



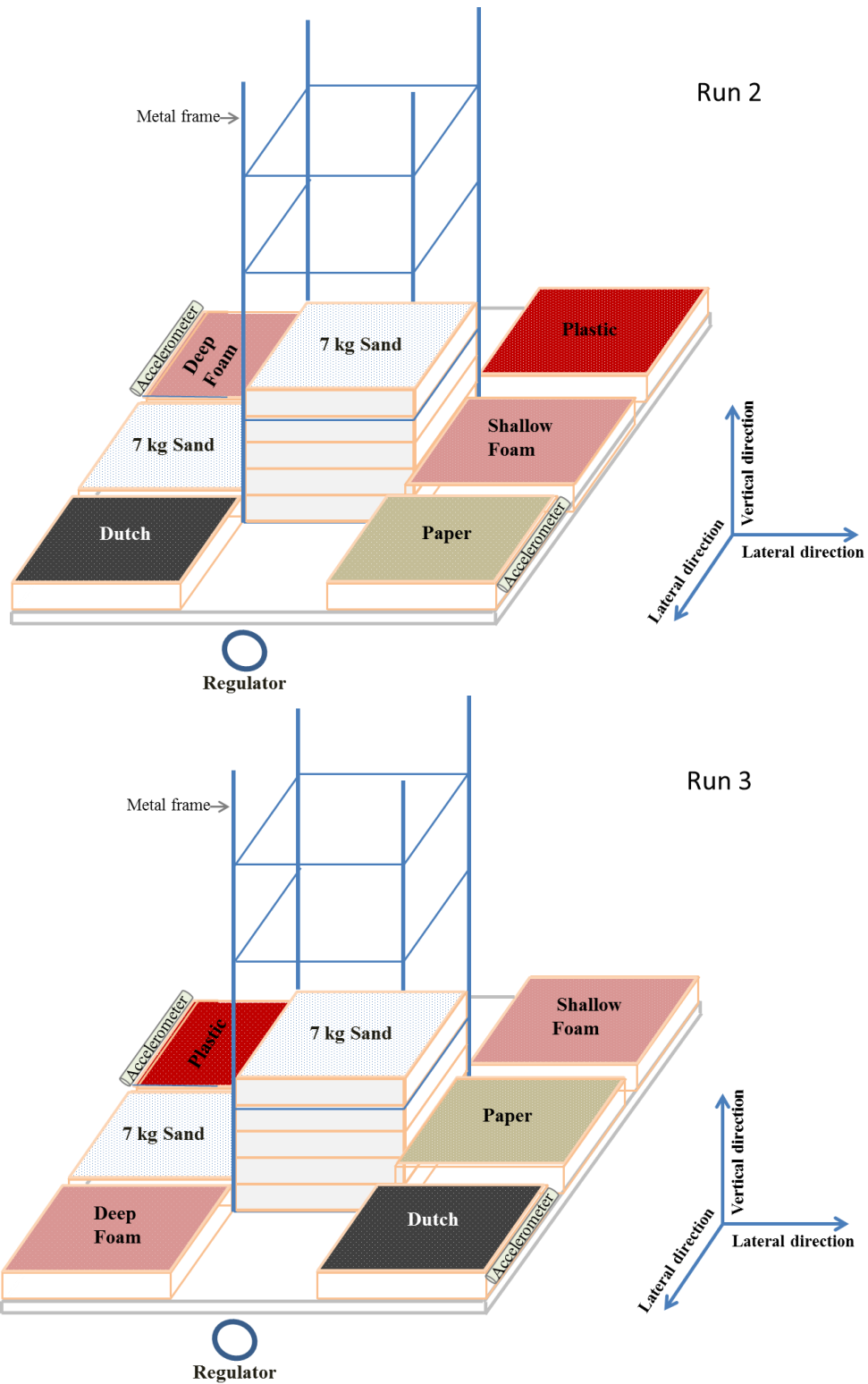


Figure 1. Schematic diagram showing the arrangement of liners in the 3 runs of the vibration table.

The rotary regavolt of the regulator was set at 74%, resulting in a speed of 540 rpm (9 Hz), as measured using a digital tachometer (Model TL 9936, JEM Tools). Accelerometers were positioned as shown in Figure 1 to measure acceleration in three directions. The accelerometers were set at 32 Hz, 5 min and 10 s for burst rate, burst interval and burst duration, respectively, using MAT logger commander software. The sensor used in this experiment was a 3-axis MAT-1 accelerometer, with memory capacity of 3.9 GB and acceleration in the range of -2 g to +2 g and maximum frequency of 64 Hz. The acceleration due to gravity (1 g) was subtracted from the data, and the acceleration level was evaluated using root mean square (RMS).

Statistical analysis

Data analysis was performed using GenStat® (Version 16.1, VSN International Ltd). One-way ANOVA and LSD comparison at 95 % level were conducted.

Results and discussion

Figure 2 shows a typical example of acceleration data in the vertical, longitudinal and lateral directions during the experiment. The frequency recorded from the accelerometer was the same as measured on the vibration table platform (9 Hz). It can be seen that acceleration occurred frequently in the vertical direction and ranged between 0.9 and -0.9 g, generating a RMS acceleration of 0.5 g. Vibration levels measured in the lateral and longitudinal direction were very low (0.03-0.04 g).

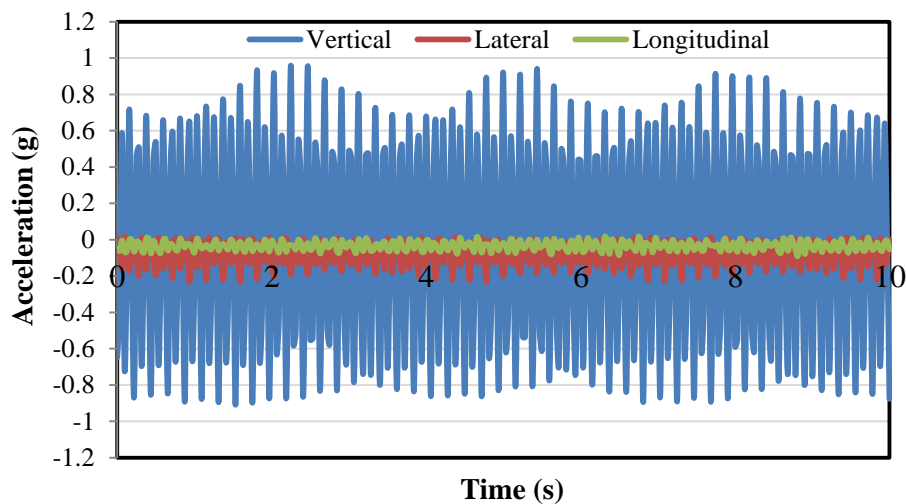


Figure 2. Typical acceleration data over time as recorded by the accelerometer.

Figure 3 presents the physical damage of mangoes packed with different liners after being vibrated at 9 Hz on the table for three hours. Mangoes packed in shallow foam and Dutch liners showed greater severity of physical damage while fruit packed with a paper liner showed the lowest levels of damage. Those packed with plastic liner and deep foam gave a moderate incidence of physical damage. These results were also reflected in the overall visual appeal of the trays of fruit (Figure 4). It was observed that fruit packed in tray liners with deeper indentations showed less rubbing of fruit against other fruit and the tray wall, resulting in reduced incidence of physical damage. It is likely that the low levels of damage shown with the paper liner could be attributed to the depth of the indentations in this tray type, combined with the cushioning properties of the material. Testing under commercial conditions would be required to confirm the benefits shown in this simulation. For example, the benefits of these paper liners in practice could be impeded by the ability of paper to absorb moisture, with associated loss of strength.

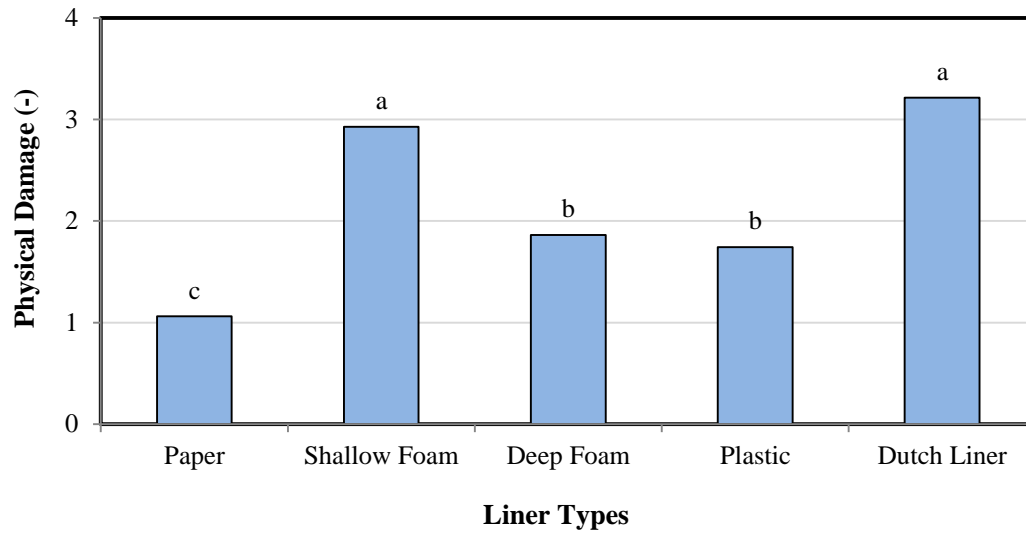


Figure 3. Physical damage of mangoes packed with different liners following three hours on vibration table. Means (bars) with the same letter indicates no statistically significant difference at $P < 0.05$ ($n=42$).

The effect of the tray liners on USB could not be observed, as the mangoes used in this trial were grown in Queensland, and were therefore not susceptible to under skin browning. Further research would be required, using mangoes susceptible to USB, to confirm whether the benefits of reduced physical damage would also confer reductions in USB.



Figure 4. Physical damage resulting from 3 hours of vibration, in various tray liners; paper (A), shallow foam (B), deep foam (C), plastic (D) and the Dutch inverted suspension liner (E).



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Tray liner effects on the development of USB in ‘Honey Gold’ mango caused by vibration during road freight and lab simulation

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Hung van Duong, Peter Hofman, Pip Bryant, Gavin Scurr

(2016/17)

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. The development of the disorder is associated with the combination of hot growing and harvest conditions, physical injury to the fruit, and low storage temperatures. Previous research indicated that bubble wrap and thin plastic between the fruit and the tray insert and the side of the tray can reduce USB in commercial consignments, suggesting that improved tray inserts or liners may provide better benefit.

In these trials several types of tray liners were tested against the standard industry tray liner to assess the potential for reducing USB expression. 'Honey Gold' mango fruit were commercially packed into these liners, cooled to about 16°C then road-freighted in commercial refrigerated trailers from Katherine (Northern Territory) to Wamuran (50 km north of Brisbane). Vibration loggers were used to obtain vibration data during transit. A separate load of fruit was also sent to Melbourne for laboratory vibration simulation. The fruit were ripened then assessed for USB development.

There were no significant effects of tested tray liners on reducing USB incidence and severity in 'Honey Gold' mango for both commercial trials and simulation trial. However, USB development of the fruit was significantly influenced by suspension type of truck. Leaf spring suspension truck had more USB fruit and severity than air ride suspension one.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results have consistently shown an association between physical damage to fruit and the development of USB symptoms. Under commercial operations physical injury resulting in USB typically occurs through vibration damage during road transport from packing shed to distribution centre, over distances of 2000-3000 km. During transit, vibration is greatest directly over the truck axles, and vibration acceleration increases as it is transmitted through boxes or trays on a pallet (Thompson, 2007). Damage is usually most severe in fruit located in the uppermost boxes near the rear of a trailer (Fischer, 1989; Hinsch et al., 1993; Thompson, 2007). Previous studies have shown that the peak of vertical acceleration often occurs in the range of 2.5-9 Hz and 0.25-0.92 G and that vibration in this range typically inflicts the most damage to the produce (Berardinelli et al., 2005; Hinsch et al., 1993; Zhou et al., 2007). Vibration levels are dependent on the vehicle speed, road condition, packaging material and suspension type (Chonhenchob and Singh, 2003; Hinsch et al., 1993; Jarimopas et al., 2005).

Well-designed tray liners can help reduce the physical damage resulting from vibration by providing cushioning and by preventing movement of the fruit. The protection of fruit against vibration damage in transit has shown potential to reduce USB, with bubble wrap around fruit reducing USB incidence from 50% to 8% (Marques et al., 2012). While this degree of protective packaging would not be economically feasible, the results demonstrate the advantage of exploring options for more protective tray liners.

The typical tray liner currently used in the mango industry is composed of thin, relatively rigid polyethylene plastic, with indented cups to hold each individual fruit in place. It has been previously observed that the hard cup edges, and crinkling in the base of the cup are potential sites of physical damage during transportation. Previous commercial trials comparing the standard liner with a shallow indented foam liner showed that the foam liner reduced damage to the base of the fruit, but resulted in more damage on the sides. This damage was thought to be due to increased rubbing against other fruit and the tray sides. It was proposed that a deeper profile foam liner may confer greater benefits by restricting the movement of the fruit. Suspension tray liners have shown benefits in reducing physical

damage to fruit during transport (Thompson et al., 2008). The current study was carried out to test the effect of several different packing liners, including the industry standard, corrugated paper, deeper foam and suspension style, on the USB development of mangoes caused by vibration during road transportation and by laboratory simulation based on vibration results generated from commercial trucks.



Plate 1 Typical under skin browning (USB) on 'Honey Gold' mango fruit (left), which often occurs at the contact points with other fruit, or with the side of the tray (right).

Materials and Methods

Vibration measurement in transit

'Honey Gold' fruit were transported from Katherine to Wamuran by Simon road train with two or three trailers, with a distance of over 3000 km.

Vibration data were collected from 4 trailers on different three trucks. A vibration logger (Slamstick C, Mide Technology USA) was mounted to I beam on truck chassis on the left side of back axles of the trailer and an external V44 battery (Voltaic system, USA) was used to connected to the logger to provide additional power for recording data within a long journey. Vibration accelerator (Slamstick X, Mide Technology USA) was attached to top 16th tray of second last pallet from rear, where tray liner trial was placed. The information about truck/trailer, date, and suspension type and logger positions is shown in Table 1 and Figure 1.

Vibration loggers measured the acceleration in vertical, longitudinal and lateral directions. Data were recorded continuously at sampling rate of 760 Hz for the Slamstick C (truck chassis vibration) and 1000 Hz for the Slamstick X (tray vibration). The vibration data were transferred to computer for analysis using specially-developed computer software and the data was presented as power spectral density (PSD). In addition, GPS trackers (GPT3G003, OzSpy, Australia) were attached to back of the trailers to monitor actual truck location (Figure 1).

Table 1. Information on truck and logger location for collecting vibration data

Truck	Trailer	Logger type	Date/Period	Suspension type	Logger location
Truck 1	2nd	Slamstic C	18:00 24 Nov - 8:00 27 Nov	Air	I Beam on trailer chassis
	2nd	Slamstic X			Top tray, second last pallet from rear
Truck 2	3rd	Slamstic C	21:00 25 Nov - 13:00 28 Nov	Leaf- spring	I Beam on trailer chassis
	3rd	Slamstic X			Top tray, second last pallet from rear
Truck 3	1st	Slamstic C	18:30 01. Dec - 7:20 04 Dec	Air	I Beam on trailer chassis
	2nd	Slamstic C		Air	I Beam on trailer chassis

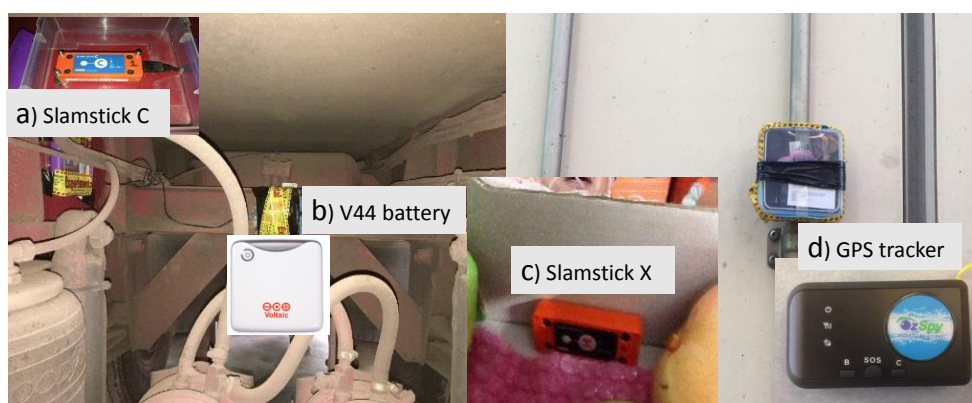


Figure 1. Measurement devices used in this study; (a) vibration logger Slamstick C mounted to I beam, (b) Voltaic battery connected to logger, (c) vibration logger Slamstick X attached to top tray, and (d) GPS tracker mounted to the rear of the truck.

Commercial tray liner trial

Treatments

This trial was conducted on 'Honey Gold' mango fruit harvested commercially at Fox Rd, Katherine (Northern Territory) in late November 2016. The trial was carried out to test the effect of different tray liners on USB development during the transport. The tray liner types and sources are presented in Table 2.

Table 2. Tray liner types and sources/providers

Liner type/materials	Count	Source
Standard plastic	14	Pinata Ptd
Soft blue deep foam from China	14	Pinata Ptd
Shallow soft foam	14	Pinata Ptd
Soft pink/white deep foam	14	Pinata Ptd
New corrugated paper	14	Orora Ltd
Plastic suspension	14	Dutch company
New paper tray	14	Robert Cullen Ltd, UK
Thin plywood 4mm thickness	-	The Bunker
Bubble wrap (pink)	-	Pinata Ptd
Bubble wrap (blue) 375 mm width	-	Officework

Eight treatments (1-8) were tested in each truck and replicated on 3 trucks. Due to the shortage of tray liners provided by Orora Ltd., and Robert Cullen from UK, there was replacement by bubble wrap (pink) in the treatment 4 of the truck 2 and bubble wrap (pink and blue) in the treatment 4 and 8 of the truck 3. The idea of putting shallow soft foam liners on the top tray (treatment 2) was to prevent damage caused by fruit rubbing against cardboard tray on the above layer, and the thinking of using thin plywood underneath plastic liner was to stop fruit bouncing during the transport. Details of treatments are described below:

For truck 1

1. Standard plastic liner
2. Standard plastic liner + Top foam layer
3. Thin ply under standard plastic liner
4. Corrugated tray liner from Orora
5. New soft blue deep foam liner from China
6. Soft pink/white deep foam liner
7. Dutch suspension liner
8. New paper liner from the UK.

For truck 2

- 1- Standard plastic liner
- 2- Standard plastic liner + Top foam layer
- 3- Thin ply under standard plastic liner
- 4- Commercially-used bubble wrap (one layer)
- 5- New soft blue deep foam liner from China
- 6- Soft pink/white deep foam liner
- 7- Dutch suspension liner
- 8- New paper liner from the UK.

For truck 3

- 1- Standard plastic liner
- 2- Standard plastic liner + Top foam layer
- 3- Thin ply under standard plastic liner
- 4- Commercially-used bubble wrap (one layer)

- 5- New soft blue deep foam liner from China
- 6- Soft pink deep foam liner
- 7- Dutch suspension liner
- 8- Bubble wrap at bottom and on top (2 layers).

Following commercial harvest and grading, size 14 fruit were packed into liner treatment trays, eight liners per treatment so there was a total of 64 trays. Each tray contained a ready-inserted treatment liner (1-8). The fruit was packed continuously in treatment order (1-8) until all 64 trays were completed. The treatment trays were then randomly arranged into layers 2 to 5 (from the top) of two pallets, with 1 tray of each treatment in each pallet layer (Figure 2). Non-treated fruit trays were packed on the top layer of the pallet. Please noted that one of treatment pallets (No 2) in the truck 2 was dispatched before assessment by accident.



Figure 2. Diagram showing liner tray arrangement in the pallet

Fruit were stored in the packing shed at about 14°C for 2 or 3 days to maximize the potential for USB expression, and were then transported by commercial, 20 pallet refrigerated trailer (16°C set temperature) by road to Wamuran (about 50 km north of Brisbane). The pallets were located over the rear axle of the trailer to maximize vibration damage. At Wamuran, the fruit were ripened according to normal commercial practice, which included several days of ethylene treatment at about 20°C. The fruit were assessed close to eating ripe for percentage of USB development and severity caused by vibration during transport using the following rating scale:

- 0=nil,
- 1=up to 1 cm²,
- 2=1 to 3cm²,
- 3=3 to 12cm² (104),
- 4=>12cm² (10%) and <25%,
- 5=>25% of the fruit surface area affected.

Laboratory vibration trial

'Honey Gold' Fruit was commercially harvested at Fox Rd, Katherine (Northern Territory) on Tuesday night or early Wednesday morning 29-30 November 2016. Fruit (class 2) were commercially packed in 5 kg tray on Wednesday afternoon (30.11.16) and selectively re-packed into 16 by 7.5 kg trays with 14 fruit per tray, with standard black liner as per normal commercial packing configuration and fruit weights per tray. The only deviation from commercial practice was each fruit placed in a plastic bag as "slip sheet" for each fruit to minimise vibration damage during transport to Melbourne. The top half of each fruit was exposed to prevent modified atmospheres around the fruit. The fruit was stored overnight at 16 °C commercial room. A button logger No 5 was wrapped in one layer of bubble wrap and inserted into one of the trays to monitor temperature. Fruit was taken to Darwin airport in air conditioned car and airfreighted to Melbourne on Thursday afternoon (01.12.16). The fruit arrived in Melbourne airport on Thursday night and were collected at about 9 am on Friday morning, then were taken by air conditioned car to the Orora Research Laboratories (Scoresby) and placed at 14°C until Monday morning 5th December 2016. Prior to exposing to vibration table, the fruit were removed from the plastic bag. Due to the limited number of fruit

and shortage of tray liners, the fruit were re-packed into the liner treatments which correspond to some of the treatments conducted in commercial trial, as follows:

- Standard plastic liner (control-unshaken)
- Standard plastic liner + (treatment 1)
- New soft blue deep foam liner from China (treatment 5)
- Soft pink/white deep foam liner (treatment 6)

Each tray and liner had 14 fruit, and there were four trays (replications) per treatment. Each treatment was placed as a single column on the vibration table, with tray 1 (rep 1) placed on the bottom and tray 4 on the tops. There were three columns, with one for each treatment, and four layers.

Based on analysis of trailer vibration data from Katherine to Brisbane, and laboratory tests at Victoria University, a treatment regime of 0.25 g RMS for 8 hours was considered sufficient to induce USB and allow treatment differences to be expressed. The acceleration of 0.25 g was achieved by using a displacement of ± 9.3 mm on the vibration table, and the treatment was applied at 12°C and 85% RH. A Lansmont model 7000-10 vibration test machine, with a 64 mm peak to peak stroke was used.

Following vibration the trays were held at 13°C for a further six days. They were then ripened at 23°C, and assessed for USB development as per above-mentioned rating at the firm ripe to soft ripe stage on 14th December.

Statistical analysis

For commercial tray liner trial, data was analysed in individual truck and cross over three truck. Data analysis was performed using GenStat® (Version 16.1, VSN International Ltd). One-way and two – way ANOVA and LSD comparison at 95 % level were conducted.

Results and discussion

Vibration measurement in transit

The data obtained from vibration loggers were analysed to determine vertical acceleration in RMS and power spectral density (PSD) levels of vibration associated with a given frequency. Figure 3 and Figure 4 show the results of acceleration and PSD obtained from representative 6-hour segments for I beam vibration whereas Figure 5 and Figure 6 present vibration data measured at the top tray of second last pallet from rear. From these graphs, it can be seen that for both trucks significant vibrations from I beam chassis existed in the 2, 12- 20 and 60 Hz frequency while frequency range at the top tray was 10-20 Hz. In addition, the levels of RMS (0.15 g) measured from I beam chassis in truck 1 which has air ride suspension was significantly smaller the level of RMS (0.24 g) obtained from truck 2 equipped with leaf spring suspension. This finding was in agreement with previous study by Garcia-Romeu-Martinez et al. (2008). Current outcomes also showed that vibration level measured at I beam chassis of the truck was greater than level at the top tray of the pallet. This was contrary with our last laboratory's result, suggesting that stronger vibration occurred at the top trays (Duong et al., 2016). The reason leading to this contradiction could be because vibration happened at different frequencies. The frequency range was 10-20 Hz on the truck while it was set at 7 Hz for laboratory test.

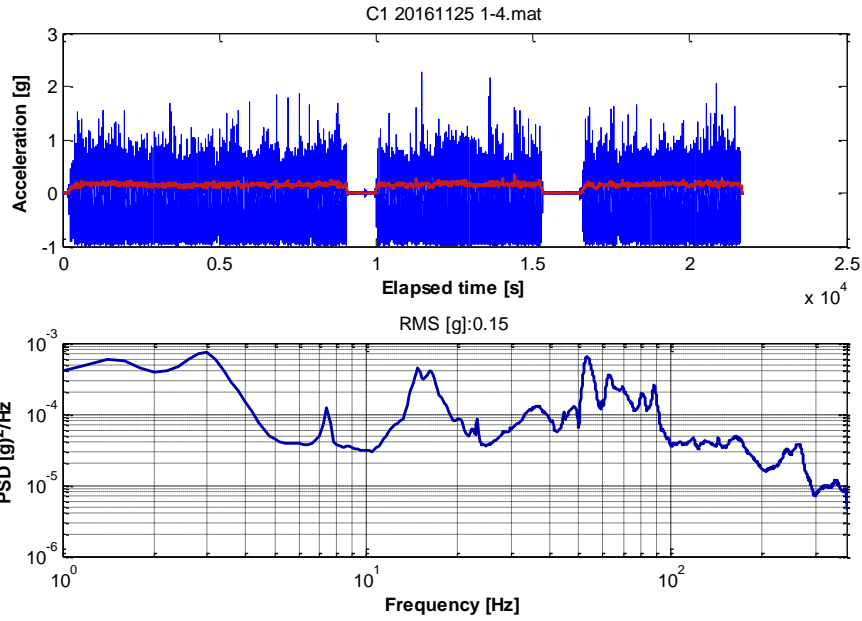


Figure 3. Acceleration and PSD of selected six-hour representative segment measured from I beam chassis in truck 1 trailer 2.

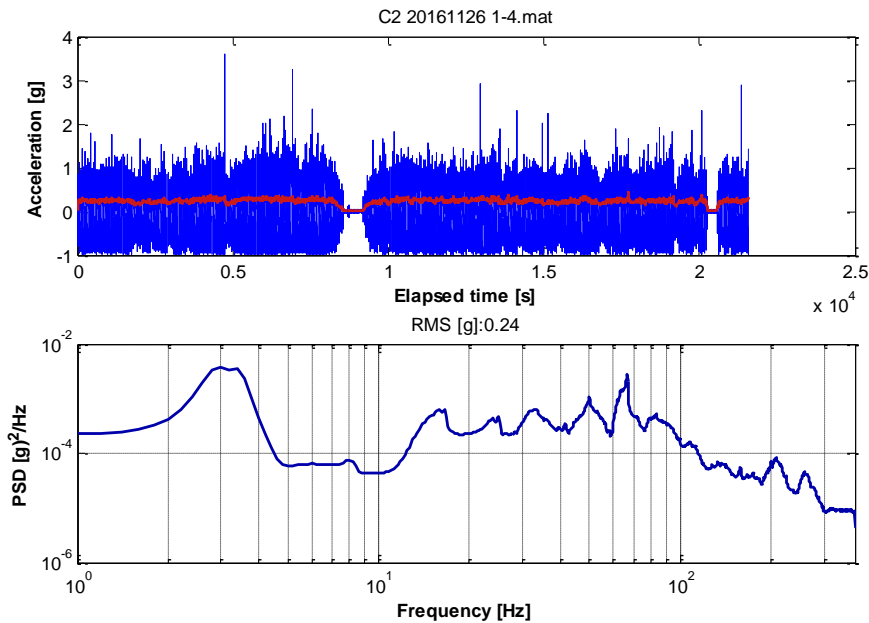


Figure 4. Acceleration and PSD of selected six-hour representative segment measured from I beam chassis in truck 2 trailer 3.

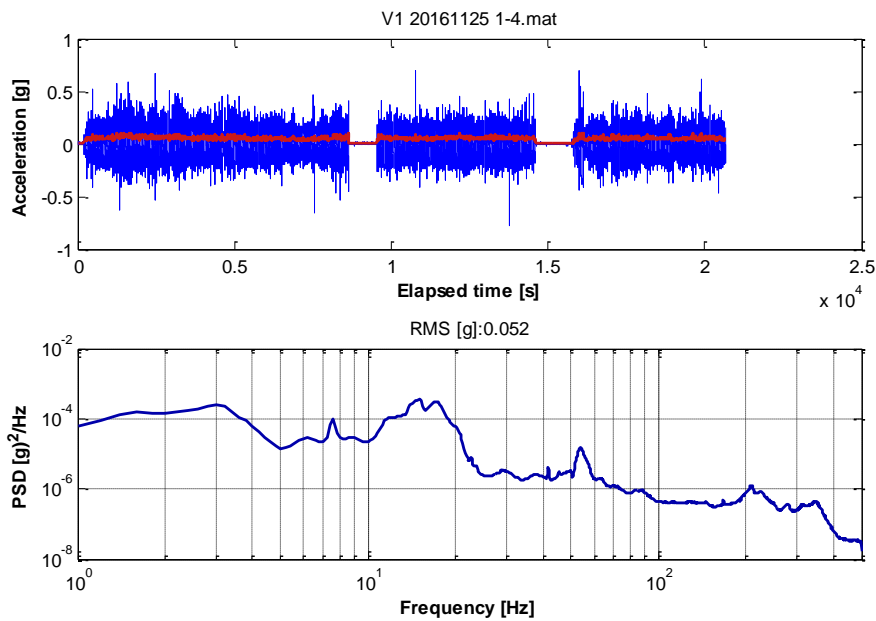


Figure 5. Acceleration and PSD of selected six-hour representative segment measured from the top tray in truck 1 trailer 2.

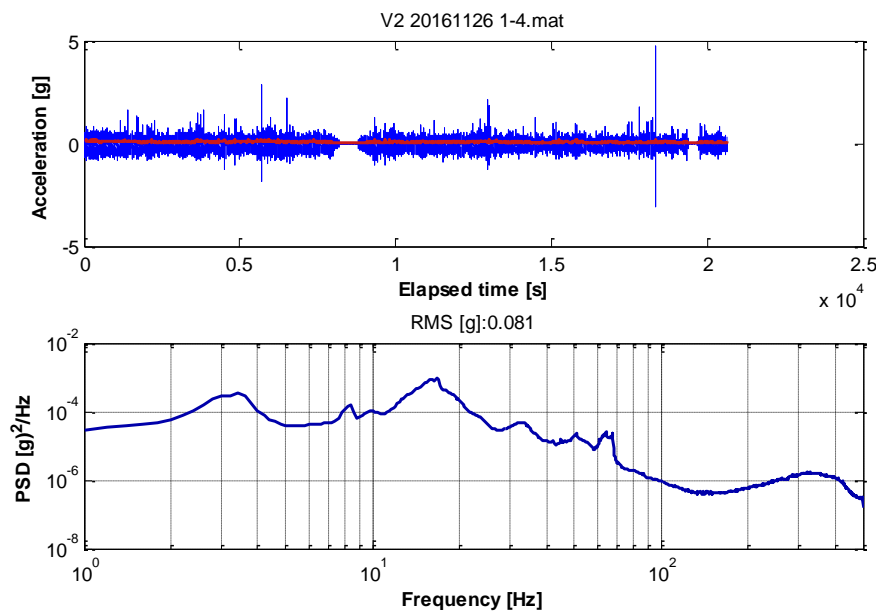


Figure 6. Acceleration and PSD of selected six-hour representative segments measured from the top tray in truck 2 trailer 3

Commercial tray liner trial

Table 3 shows the percentage of fruit having USB expression and its severity level after being packed by different types of tray liners during transport from Katherine to Wamuran within 3 various trucks. The results indicated that there was no significant difference in percentage of fruit with any USB and USB severity among treatments in truck 1 and 2. However, a significant difference in average USB severity on

affected fruit (1-5) was found among treatments within truck 3, indicating that pink soft deep foam liner (treatment 6) reduced USB development as compared with others. Significant effect of treatment 5 on USB appearance was again confirmed when data of USB severity on affected fruit (1-5) was analyzed cross all three trucks (Table 4). There was a significant difference in USB incidence and severity among three trucks. Truck 2, which has leaf spring suspension, had higher percentage fruit with USB and more severe USB than fruit in truck 1 and 3 which were equipped with air ride suspension (Table 5). This result was evidenced by vibration data collected from the trucks, suggesting that the fruit transported by truck with leaf spring suspension were exposed more to vibration than fruit transported by air ride suspension truck. As a result, the fruit had more USB incidence and severity.

Table 3. Under skin browning (USB) severity on 'Honey Gold' mango fruit packed with different types of tray liners on three different trailers and transported by truck from Katherine (Northern Territory) to Wamuran (South East Queensland).

Trailer	Treatment	% of fruit with any USB	Average USB severity on all fruit (0-5)	Average USB severity on affected fruit (1-5)
		Mean	Mean	Mean
1	Standard plastic liner	8.9	0.20	2.62
	Standard plastic liner + Top foam layer	8.9	0.20	2.38
	Thin ply under standard plastic liner	10.7	0.27	2.47
	Corrugated tray liner from Orora	13.4	0.36	3.07
	New soft blue deep foam liner from China	17.9	0.42	2.41
	Soft pink/white deep foam liner	15.2	0.37	2.35
	Dutch suspension liner	12.5	0.29	2.20
	New paper liner from the UK.	17.9	0.48	2.70
	SE (mean)	3.36	0.09	0.24
2	Standard plastic liner	21.4	0.59	2.75
	Standard plastic liner + Top foam layer	26.8	0.88	2.85
	Thin ply under standard plastic liner	23.2	0.73	3.19
	Commercially-used bubble wrap (one layer)	28.6	0.80	2.79
	New soft blue deep foam liner from China	16.1	0.54	3.42
	Soft pink/white deep foam liner	14.3	0.39	2.75
	Dutch suspension liner	33.9	1.10	3.51
	New paper liner from the UK	26.8	0.73	2.67
	SE (mean)	6.19	0.20	0.32
3	Standard plastic liner	16.10	0.48	2.82 a
	Standard plastic liner + Top foam layer	15.20	0.44	2.92 a
	Thin ply under standard plastic liner	17.90	0.56	3.19 a
	Commercially-used bubble wrap (one layer)	23.20	0.70	2.95 a
	New soft blue deep foam liner from China	13.40	0.36	2.58 a
	Soft pink/white deep foam liner	5.40	0.11	1.75 b
	Dutch suspension liner	15.20	0.47	3.15 a
	Bubble wrap at bottom and on top (2 layers)	17.90	0.51	2.85 a
	SE (mean)	4.30	0.14	0.21

Means with the same letter or without letter in the same column are not significantly different at the P= 0.05 level (n=112 fruit for truck 1, 3 and n=56 fruit for truck 2)

Table 4. Average under skin browning (USB) severity on 'Honey Gold' mango fruit packed with different types of tray liners cross all three trailer and transported by road from Katherine (Northern Territory) to Wamuran (South East Queensland)

Treatment	% of fruit with any USB	Average USB severity on all fruit (0-5)	Average USB severity on affected fruit (1-5)
	Mean	Mean	Mean
Standard plastic liner	14.29	0.39	2.66 a
Standard plastic liner + Top foam layer	15.00	0.43	2.59 ab
Thin ply under standard plastic liner	16.10	0.48	2.92 a
New soft blue deep foam liner from China	15.71	0.42	2.65 a
Soft pink/white deep foam liner	11.07	0.27	2.21 b
Dutch suspension liner	17.86	0.53	2.86 a
SE (mean)	2.37	0.07	0.16

Means with the same letter or without letter in the same column are not significantly different at the P= 0.05 level (n=280 fruit)

Table 5. Under skin browning (USB) severity on 'Honey Gold' mango fruit affected by suspension type of truck during transport from Katherine (Northern Territory) to Wamuran (South East Queensland).

Trailer	Suspension type	% of fruit with any USB		Average USB severity on all fruit (0-5)		Average USB severity on affected fruit (1-5)	
		Mean	SE	Mean	SE	Mean	SE
1	Air suspension	12.35 b	1.52	0.29 b	0.04	2.37 b	0.14
2	Leaf spring	22.62 a	2.15	0.70 a	0.06	3.08 a	0.20
3	Air suspension	13.84 b	1.52	0.41 b	0.04	2.72 ab	0.14

Means with the same letter are not significantly different at the P= 0.05 level (n=672 fruit for truck 1, 3 and n=336 fruit for truck 2)

Laboratory vibration trial

Figure 7 shows temperature to which fruit exposed during the transport and experiment. Fruit after arriving in Melbourne were maintained at 14°C for two days. The fruit were vibrated on the vibration table for 8 h at 12 °C and then stored at 13 °C for 6 six days to assess fruit USB development.

There was no significant difference in percentage of fruit with USB and average USB severity on affected fruit (1-5) amongst the treatments (Table 6). However, the average USB severity of all fruit (0-5) packed in plastic trays without being shaken was significantly lower than those being vibrated.

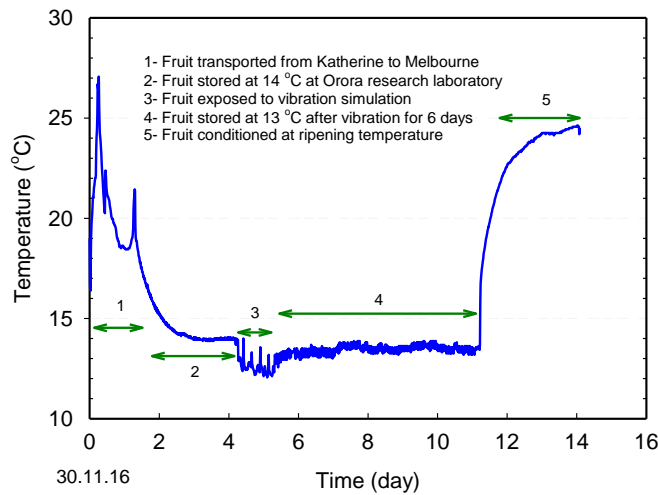


Figure 7. Fruit temperature during fruit transport and laboratory simulation

Table 6. Under skin browning (USB) severity on ‘Honey Gold’ mango fruit packed with different types of tray liners after being shaken on vibration table.

Treatment	% of fruit with any USB	Average USB severity on all fruit (0-5)	Average USB severity on all fruit (1-5)
	Mean	Mean	Mean
Standard plastic liner (control)	1.80	0.02 b	1.00
Standard plastic liner (T1)	17.90	0.38 a	1.81
New blue deep foam (T5)	10.70	0.16 ab	1.60
White soft deep foam (T6)	7.10	0.09 ab	2.15
SE (mean)	4.22	0.07	0.33

Means with the same letter or without letter in the same column are not significantly different at the P= 0.05 level (n=56)

Conclusions

Based on the results obtained from these experiments, the following conclusions were drawn as follow:

- Significant vibration occurred during transport was in 10-20 Hz frequency range, regardless of suspension type of the truck.
- The severity of vibration level increased with truck equipped with leaf spring suspension. The vibration in the top tray of the pallet was lower than that in I beam chassis.
- Effect of tray liners on USB development in both commercial trials and laboratory simulation was not found.
- Suspension type of the truck affected UBS incidence and severity on “Honey Gold” mango. Air ride suspension significantly reduced USB development as compared with leaf spring one

Tray liner effects on the development of USB in ‘Honey Gold’ mango caused by vibration during road freight and lab simulation



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**Engineered Packaging and
Distribution Research Group**

EFFECTS OF VIBRATION AND TEMPERATURE ON HONEY GOLD MANGOES

For the

**Queensland Department of Agriculture and
Fisheries**

ERCU571 – April 2017

Report written by: Vincent Rouillard M.Eng (*VicMelb*) PhD (*Monash*)

The work presented in this report was overseen and approved by:

V. Rouillard PhD (*Monash*) M.Eng (*VicMelb*) FIEAust

A handwritten signature in black ink, appearing to be 'V. Rouillard', followed by a colon.

18 April 2017

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1 INTRODUCTION

At the request of the Queensland Department of Agriculture and Fisheries, the Engineered Packaging and Distribution Research Group at Victoria University undertook an investigation into the effects of vibrations on the under-skin browning (USB) of Honey Gold mangoes during transport between Katherine, NT and Brisbane, Qld. This report describes the procedures and results from exploratory and simulated vibration experiments as well as the analysis of vibration data recorded on a number of journeys between Katherine and Brisbane.

2 EXPLORATORY VIBRATION EXPERIMENTS

2.1 Aim

To observe and / or measure the behaviour of the product under various vibration frequencies and amplitudes.

2.2 Methodology

Trays of Honey Gold mangoes, placed in their original packaging trays and liners, were subjected to a range of vertical vibrations (both harmonic and random) and their motion observed visually to determine which vibration frequency / amplitude combination (if any) might be the likely cause of relative movement (hence scuffing and USB) between the fruits.

2.3 Outcomes and observations

- 11:00 Thursday Nov 17: Fruit received all in trays and standard black liner. Four trays (labelled Layer 1, 2, 3 and 4 and placed at 12 °C due to limited space in environmental chamber. The other trays were left at room temperature. Preliminary vibration tests undertaken on one unmarked/unconditioned tray to investigate resonances by exciting at various arbitrary frequencies and amplitudes. etc. Note that the individual plastic liners were removed prior to testing. This tray sample was left at room temperature after testing.
- 14:45 Friday Nov 18: The four refrigerated trays (labelled layer 1, 2, 3 and 4) were removed from the 12 °C environment and used for preliminary vibration tests. The trays were arranged in a column stack (varying the number of trays) to investigate resonances by exciting at various arbitrary frequencies and amplitudes. Note that all individual plastic liners were removed prior to testing. Results show that the tray/mango system exhibit vibration resonance within the 11 – 24 Hz frequency range as shown on video footage available [here](#). This frequency range corresponds to the unsprung mass resonant frequency (axle hop) of many transport vehicles – see frequency spectrum below. Total test duration: 1 hour.



Figure 2.1. Tray configurations for exploratory vibration experiments.

- 16:10 Friday Nov 18: Subjected the four trays (labelled layer 1, 2, 3 and 4) to artificial random vibrations modelled on a typical transport truck (ASTM Power Density Spectrum see graph below) for 1.5 Hrs. Note that only frequencies above 8 Hz were simulated as the previous experiments revealed that no significant vibration activity (resonance) occurred below this frequency. The overall level of the random vibrations was set at 0.35 g.

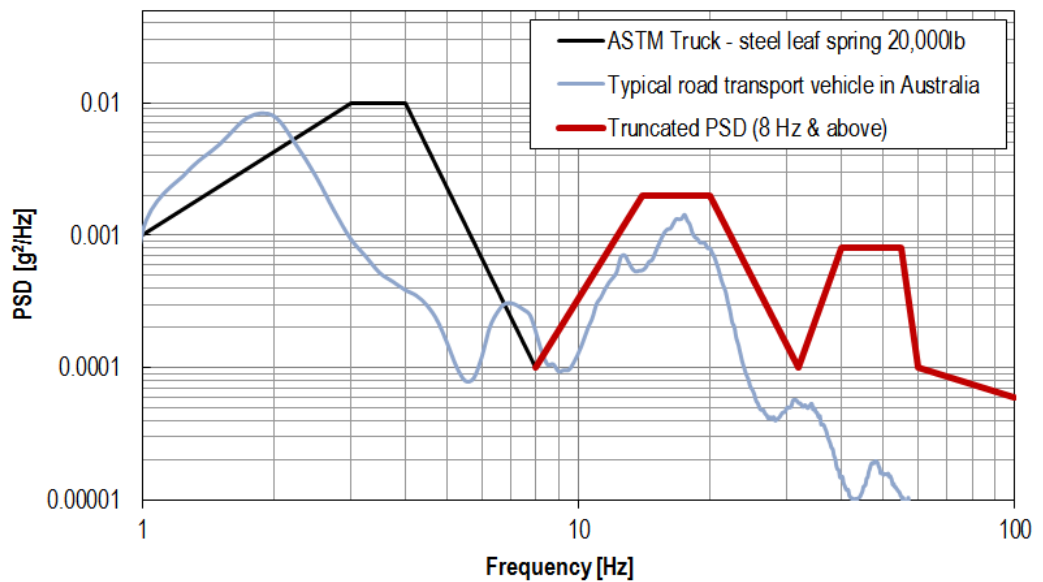


Figure 2.2: Simulated PSD along with that of a typical (generic) transport truck.

- 17:45 Friday Nov 18: Four tray samples return to environmental chamber at 12 °C.
- 9:00 Monday Nov 21: Four tray samples removed from 12 °C environment and the random vibration test resumed for another 2 Hrs making a total exposure to random vibration of 3.5 hours.
- 11:00 Monday Nov 21: Four tray samples return to environmental chamber at 12 °C.

- 12:00 Thursday Nov 24: Environmental chamber switched off and temperature allowed to return to ambient. Note that this produced a high RH environment.
- 10:00 Monday Nov 27: All tray samples were collected for inspection for evidence of USB. This showed that products in all four trays subjected to harmonic and random vibrations suffered significant levels of USB.

3 ANALYSIS OF RECORDED VIBRATION DATA – INITIAL DATA SET

3.1 Aim

To characterise the vibrations generated by the vehicles used to transport the product from Katherine, NT to Brisbane, Qld and those experienced by the product during typical journeys. This is to enable the simulation of statistically similar vibrations under laboratory-controlled conditions so that the type and level of USB can be reproduced and to evaluate the effectiveness of any changes to the design, configuration or material of the protective packaging system without having to undertake field trials repeatedly.

3.2 Preliminary Results

Because of the limited time-frame available for laboratory simulation (imposed by the availability of harvested fruit), analysis was undertaken on an initial set of vibration data which was collected by Qld DAF personnel as follows:

Table 3.1. Initial recorded vibration data

Data files ID	Start - End	Duration (Hrs)	Vehicle / location
Data Control 1 Trailer 2 (C1)	9:04, 24 Nov – 8:13, 27 Nov	71.15	Truck No.1, Trailer No. 2 (I Beam on truck chassis)
Data Control 2 Trailer 3 (C2)	21:22, 25 Nov – 12:58, 28 Nov	63.60	Truck No.2, Trailer No. 3 (I Beam on truck chassis)
Data Control 1 Trailer 2 (V1)	17:22, 24 Nov – 2:59, 25 Nov	9.61	Truck No.1, Trailer No. 2 (Top tray, second last pallet from rear)
Data Control 2 Trailer 3 (V2)	8:31, 25 Nov – 10:21, 26 Nov	25.83	Truck No.2 Trailer No. 3 (Top tray, second last pallet from rear)

Vibrations were recorded continuously at a sampling rate of 760 Hz for the Slamstick C (± 16 g) (truck chassis vibration) and 1,000 Hz for the Slamstick X (± 25 g) (top tray vibration). Due to the large amounts of data recorded for each journey, they could not initially be analysed as a whole. Instead, data was grouped in 6-hour segments then

submitted to analysis using specially-developed computer software. Figures 3.1 and 3.2 show the results of representative 6-hour segments for the two truck vibration data files.

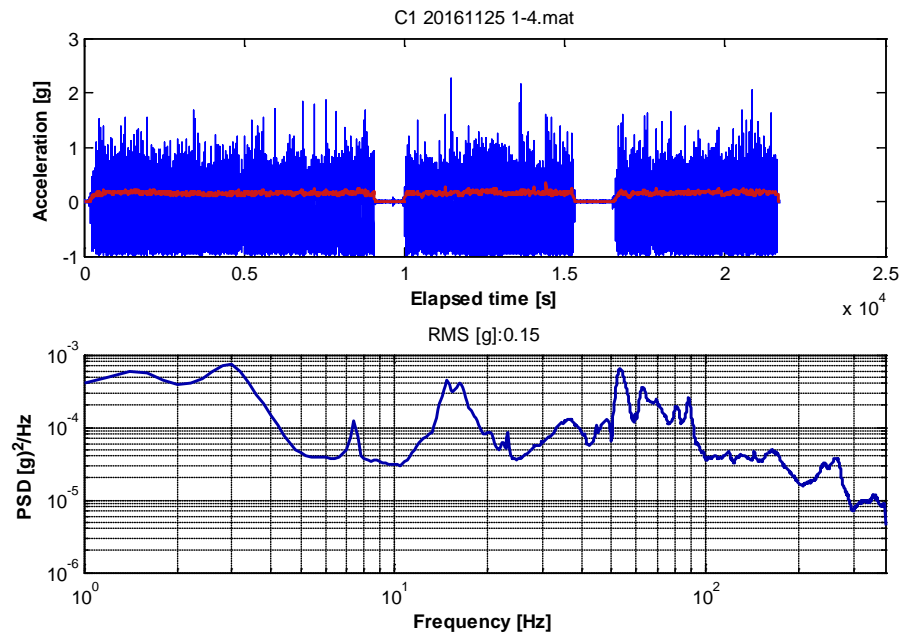


Figure 3.1: Truck 1 Trailer 2: Top: selected six-hour representative segment along with 1-sec moving RMS. Bottom: Corresponding average PSD.

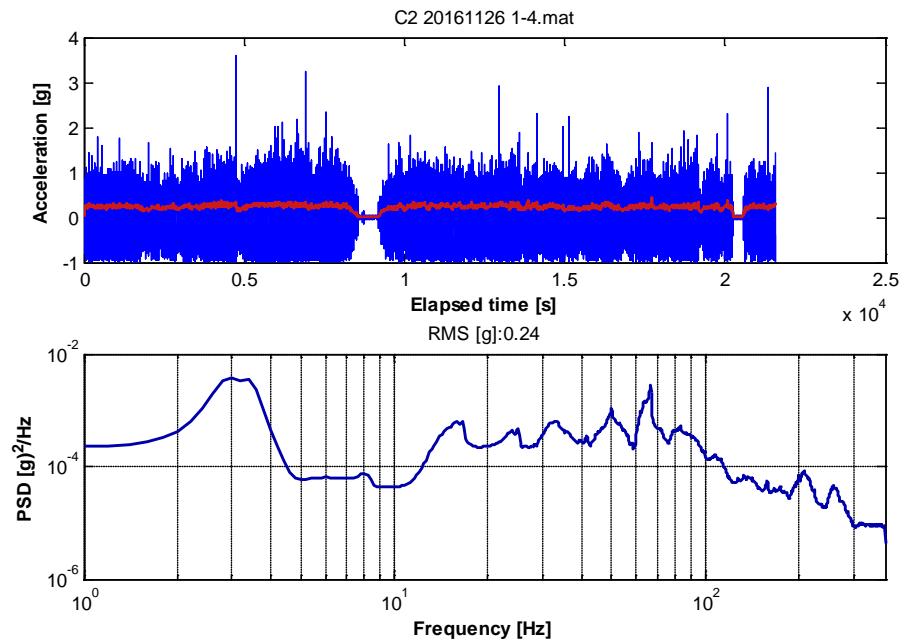


Figure 3.2: Truck 2 Trailer 3: Top: selected six-hour representative segment along with 1-sec moving RMS. Bottom: Corresponding average PSD.

Figures 3.3 and 3.4 show the results of representative 6-hour segments for the two tray vibration data files.

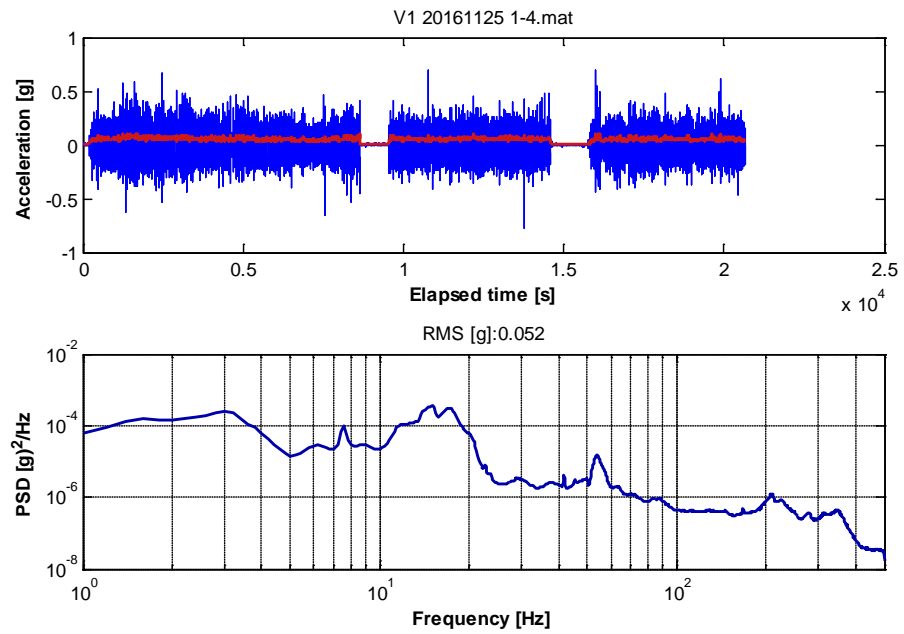


Figure 3.3: Tray response (Truck 1 Trailer 2): Top: selected six-hour representative segment along with 1-sec moving RMS. Bottom: Corresponding average PSD.

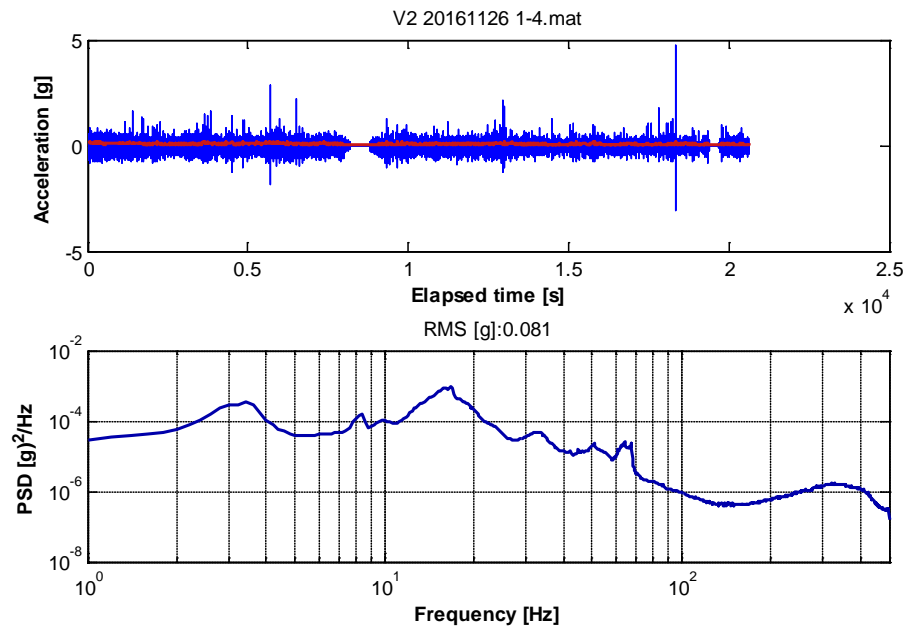


Figure 3.4: Tray response (Truck 2 Trailer 3): Top: selected six-hour representative segment along with 1-sec moving RMS. Bottom: Corresponding average PSD.

Figures 3.5 and 3.6 show the both the excitation (truck) and response (tray) acceleration PSDs for set of measurements (6-hour representative segments). From these it can be observed that:

- For Truck 1 / Trailer 2, significant vibrations exist in the 12 – 20 Hz frequency range which corresponds to the range of resonant frequencies observed from the preliminary experiments. This is confirmed by the tray PSD (pink) that are significant in the same frequency range.
- For Truck 2 / Trailer 3, although vibrations in the 12 – 20 Hz frequency are less significant, they are sufficiently severe to cause significant vibration of the tray PSD (pink) in that same frequency range.

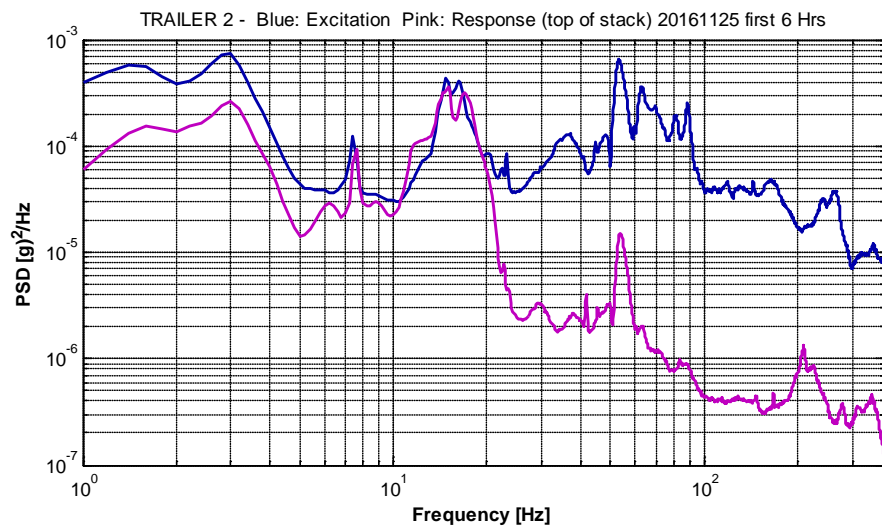


Figure 3.5: Truck (blue) and tray (pink) PSDs for Truck 1 Trailer 2.

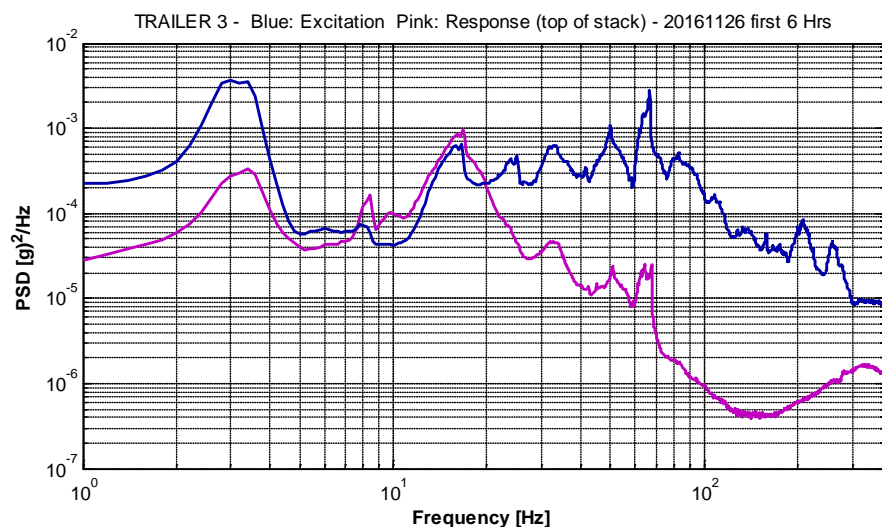


Figure 3.6: Truck (blue) and tray (pink) PSDs for Truck 2 Trailer 3.

Figure 3.7 shows that the RMS distributions for the representative 6-hour segments for all four data sets. These reveal that the average vibrations levels for Truck 1 / trailer 2 (0.15 g) are significantly lower than those of Truck 2 / trailer 3 (0.24 g). It can also be observed that the vibration of the top trays is significantly less severe than those of the vehicles and that much of this attention occurs at frequencies greater than 20 Hz.

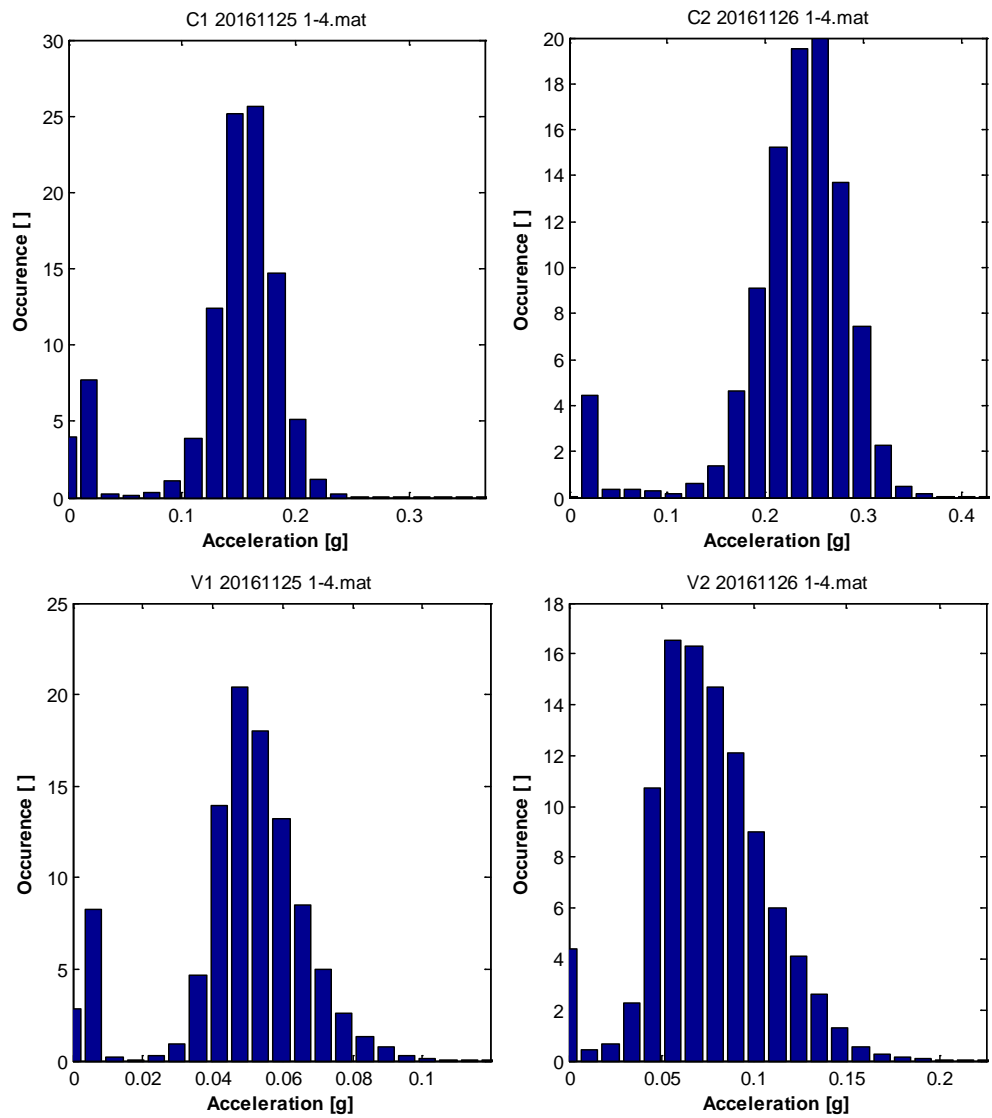


Figure 3.7: RMS distributions for selected sections of the initial records.

4 VIBRATION SIMULATION TEST

4.1 Aim

To subject samples (arranged in column stacks) to simulated transport vibrations (using a programmable vibration shaker) to establish the cause and mechanism of USB and the time it takes to generate USB. This can also be used to compare the effectiveness of various protective packaging designs.

4.2 Simulation parameters

The following simulation parameters are recommended:

- Target PSD: use the table created by taking breakpoints from the average PSD from figure 2 (Truck 1 / trailer 2). This PSD, shown in Figure 4.1, was chosen as it contains higher amplitudes in the frequency band corresponding to tray/fruit resonance.

Hz	g^2/Hz
1	0.0001
3	0.0007
5	0.00005
10	0.00003
13	0.0005
18	0.0005
24	0.00004
37	0.00014
53	0.00065
89	0.00025
200	0.000015

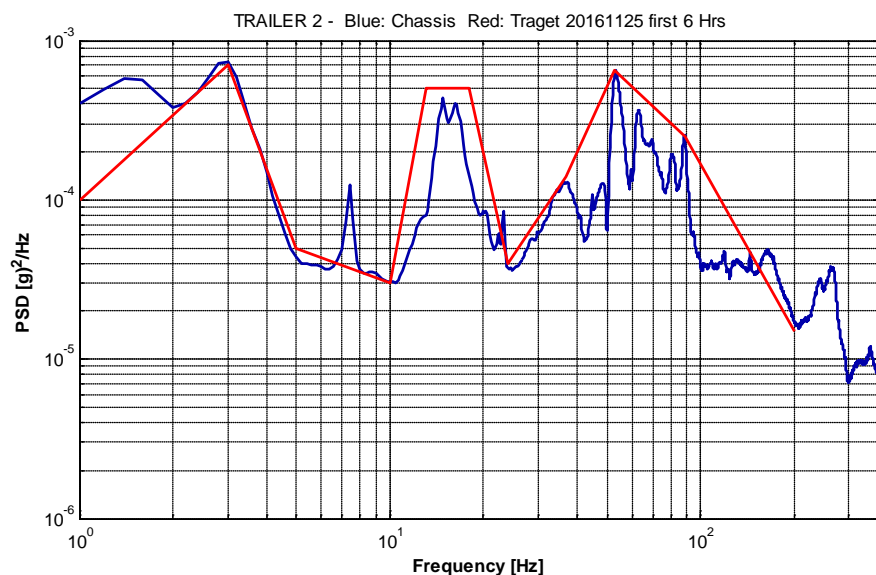


Figure 4.1: Target PSD for vibration test.

- RMS level: 0.25 g. At this level, the maximum shaker displacement (using $\pm 3\sigma$) is ± 9.3 mm. If necessary, this can be increased to accelerate the browning process.
- Duration: At this stage, there has not been enough time to analyse all the data from recorder C1. Based on the analysed segments, it appears that significant

vibrations (0.1 g rms or higher) were present throughout the trip. Based on the preliminary test undertaken at VU (random vibrations at 0.35 g rms for 3.5 Hrs), 8 hours at 0.25 g rms was expected to be sufficient to induce bruising in the samples and allow any difference between the various protective packaging design to be revealed.

4.3 Vibration test – procedure

The fruit were taken by air-conditioned car to the Orora Research Laboratories (Scoresby) and placed at 12°C until Monday morning 5th December.

The fruit were then removed from the plastic bag and re-packed into the liner treatments, as follows:

- Treatment 1: Standard black liner
- Treatment 2: White, deep profile expanded polystyrene liner
- Treatment 3: Deep profile blue liner from China
- Treatment 4: Standard black liner

Each tray had 14 fruit, and there were four trays (replications) per treatment. Three tray stacks (one each for treatments 1, 2 and 3) were placed on the vibration table with tray 1 located at the bottom of each stack and tray 4 at the top. Treatment 4 was not subjected to vibrations and used as the control.

The vibration table used was a Lansmont model 7000-10 vibration test machine with a 64 mm stroke. The shaker table is enclosed within a controllable environment, which was set to 12 degrees and 85%RH for the test. Vibration testing was completed by 11pm Monday the 5th. The samples remained in the vibration chamber overnight for 8 hours before being held at 12°C for a 6 days. The samples then ripened at 23°C, and assessed at the firm ripe or soft ripe stage on 14th December.

4.4 Results

The incidence of USB was low, most likely because the fruit were not very sensitive (combination of growing conditions, harvested at night rather than during the day, and the time from harvest to treatment). Nonetheless there are indications of a treatment effect as shown in the table below but it is uncertain if these are statistically significant.

Table 4.1 USB level after 8-hour vibration test.

Treatment	Incidence (% of fruit affected)				Average	Std Dev
	Tray no (rep)					
	1	2	3	4		
Control Black	0	0	0	7	2	4
Black	7	29	21	14	18	9
Blue	21	7	14	0	11	9
White	21	0	7	0	7	10

5 ANALYSIS OF RECORDED VIBRATION DATA – ENTIRE DATA SET

5.1 Aim

To characterise the vibrations generated by the vehicles used to transport the product from Katherine, NT to Brisbane, Qld and those experienced by the product during typical journeys. This will enable more accurate simulation of statistically similar vibrations under laboratory-controlled conditions so that the type and level of USB can be reproduced and to evaluate the effectiveness of any changes to the design, configuration or material of the protective packaging system without having to undertake field trials repeatedly. Vibration data was collected by Old DAF personnel as follows:

Table 5.1. Entire recorded vibration data summary

Data files ID	Start - End	Duration (Hrs)	Vehicle / location
Data Control 1 Trailer 2 (C1)	9:04, 24 Nov – 8:13, 27 Nov	71.15	Truck No.1, Trailer No. 2 (I Beam on truck chassis)
Data Control 2 Trailer 3 (C2)	21:22, 25 Nov – 12:58, 28 Nov	63.60	Truck No.2, Trailer No. 3 (I Beam on truck chassis)
Data Control 3 Trailer 2	17:13, 1 Dec – 7:03, 4 Dec	61.83	Trailer No. 1 (I Beam on truck chassis) on a three- trailer road train
Data Treatment 3 Trailer 1	18:20, 1 Dec – 10:05, 2 Dec	15.75	Trailer No. 2 (I Beam on truck chassis) on a three- trailer road train
Data Control 1 Trailer 2 (V1)	17:22, 24 Nov – 2:59, 25 Nov	9.61	Truck No.1, Trailer No. 2 (Top tray, second last pallet from rear)
Data Control 2 Trailer 3 (V2)	8:31, 25 Nov – 10:21, 26 Nov	25.83	Truck No.2 Trailer No. 3 (Top tray, second last pallet from rear)

Vibrations were recorded continuously at a sampling rate of 760 Hz for the Slamstick C (± 16 g) (truck chassis vibration) and 1000 Hz for the Slamstick X (± 25 g) (tray vibration).

5.2 Results

The analysis of the vibrations comprised computing the average Power spectral density (PSD), the moving rms (1-second window) for each record along with the rms distribution density and cumulative distribution. These are shown in Figures 5.1 – 5.6.

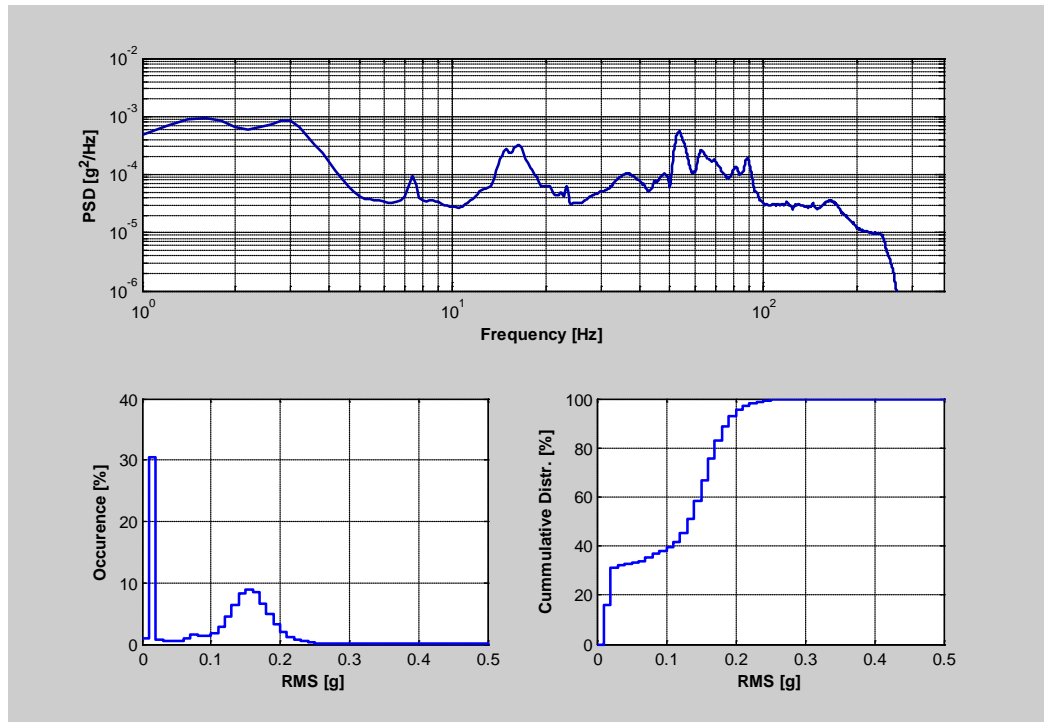


Figure 5.1 Data Control 1 Trailer 2 (C1)

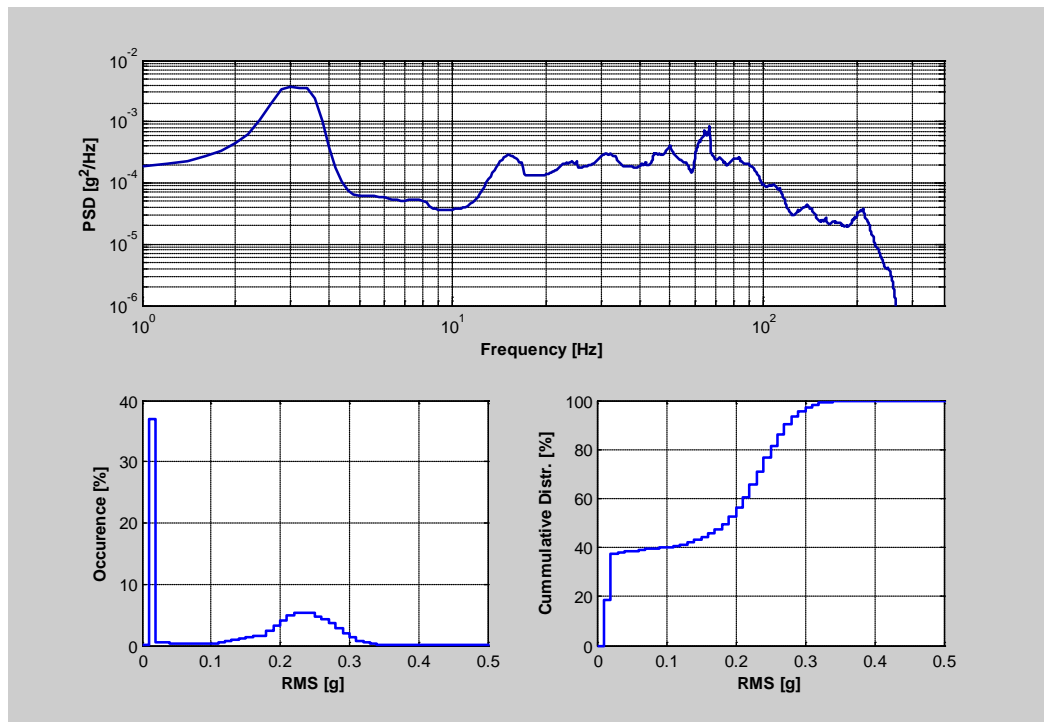


Figure 5.2. Data Control 2 Trailer 3 (C2)

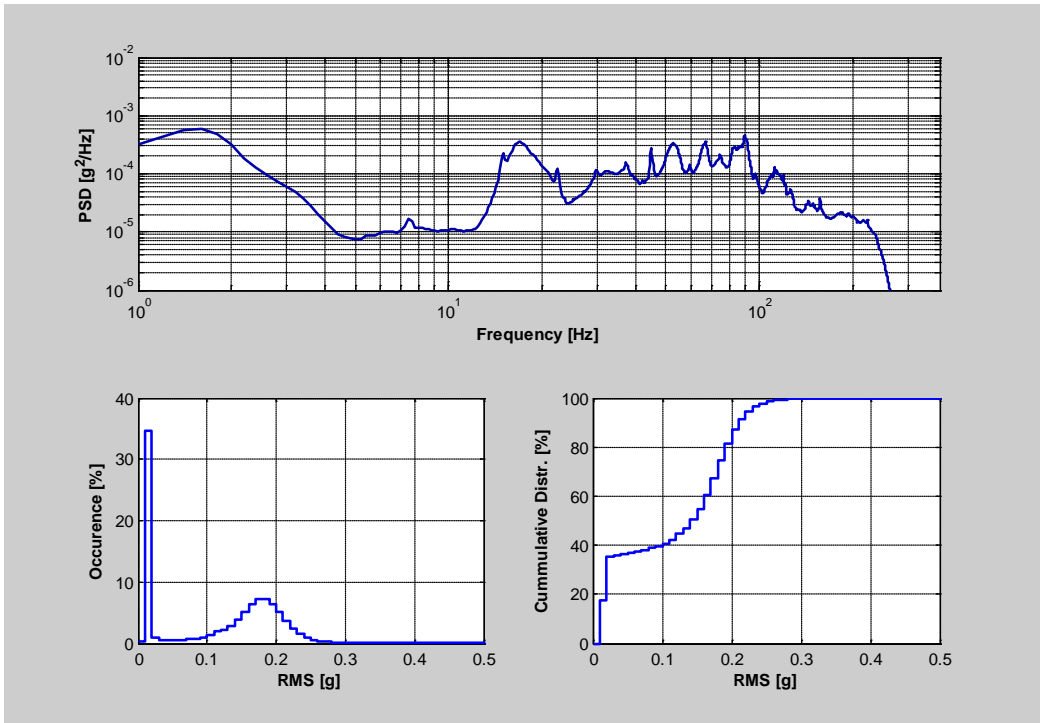


Figure 5.3. Data Control 3 Trailer 2

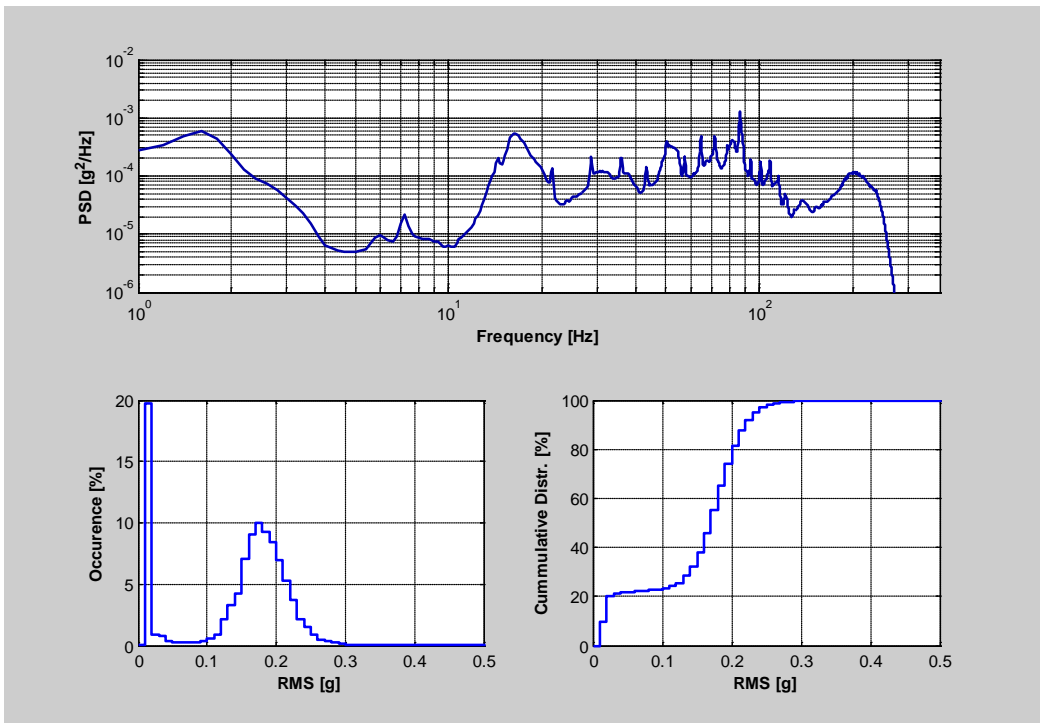


Figure 5.4. Data Treatment 3 Trailer 1

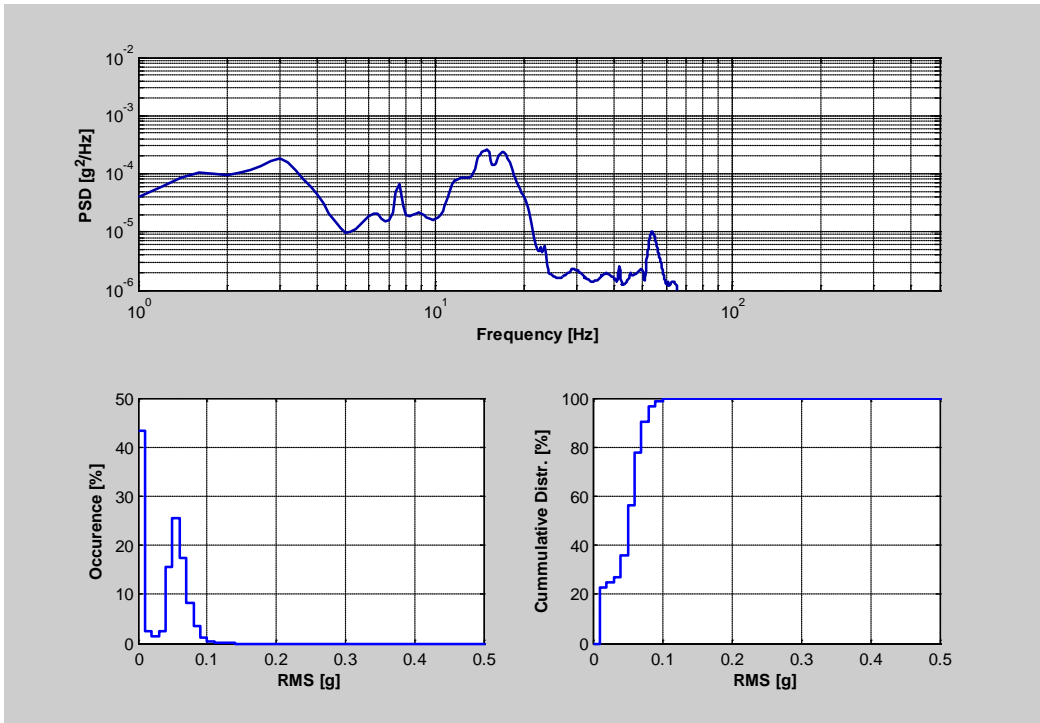


Figure 5.5 Data Control 1 Trailer 2 (V1)

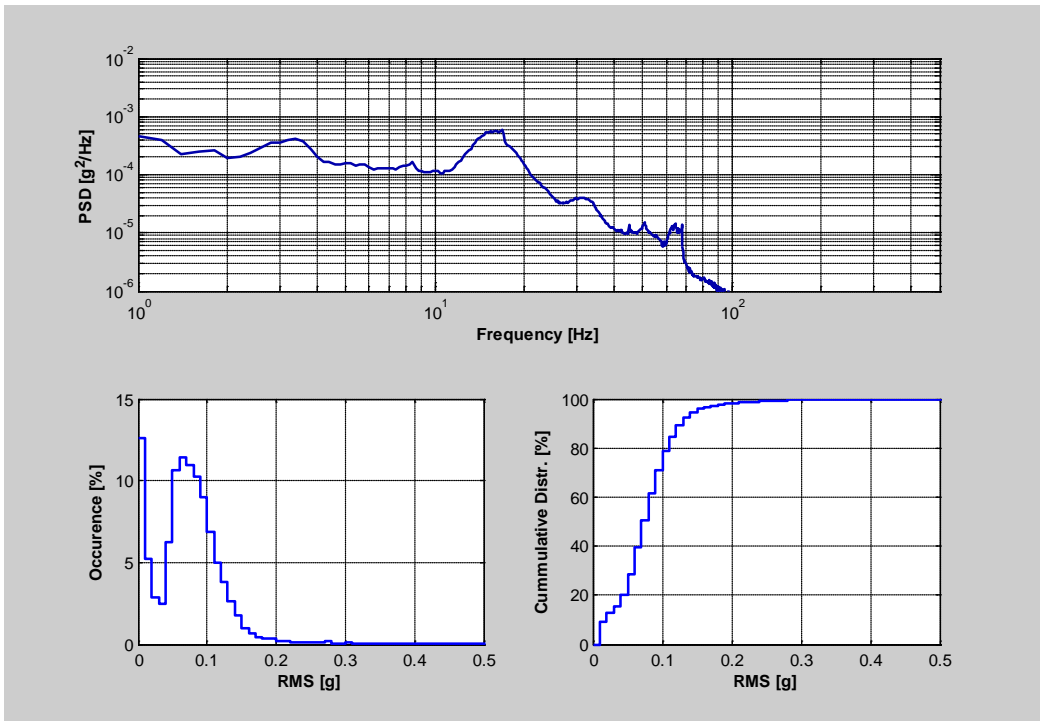


Figure 5.6. Data Control 2 Trailer 3 (V2)

Table 5.2 Vibration data summary

Data files ID	Description	Recorded Duration [Hrs]	Duration at significant vibration levels*	Median* RMS [g]	P ₉₉ RMS [g]
Data Control 1 Trailer 2 (C1)	Truck chassis	71.15	49.8 Hrs / 70%	0.15	0.25
Data Control 2 Trailer 3 (C2)	Truck chassis	63.60	41.3 Hrs / 65%	0.22	0.33
Data Control 3 Trailer 2	Truck chassis	61.83	46.4 Hrs / 75%	0.17	0.26
Data Treatment 3 Trailer 1	Truck chassis	15.75	14.2 Hrs / 90%	0.18	0.27
Data Control 1 Trailer 2 (V1)	Top tray response	9.61	5.7 Hrs / 60%	0.05	0.10
Data Control 2 Trailer 3 (V2)	Top tray response	25.83	19.4 Hrs / 75%	0.07	0.25

* Calculated after removing segments where vehicle was stationary (no on background engine vibrations)

5.3 Observations - Truck vibration.

- In all four cases, the overall vibrations (median and 99% percentile) we not found to be excessively large and are within expected levels for truck transport on sealed roads of reasonable quality (roughness).
- The spread in vibration level was found to be small indicating the absence of exceeding rough pavement sections during the journeys.
- The vibration spectra all exhibit significant vibrations in the range 12 – 20 Hz except for Data Control 2 Trailer 3 (C2) where vibration levels in that range are lower. It is very likely that these peaks in the vibration spectra correspond to the axle hop frequency of the vehicle. This is particularly significant here given the results of the exploratory tests (section 2) which show that the laden trays exhibit resonant frequencies in the region of 11 – 24 Hz. This presents an opportunity

to design a protective packaging system that will attenuate vibrations in that frequency range thus affording a means to reduce USB occurrence during transport.

5.4 Observations – Top tray vibration.

- Unsurprisingly, the overall vibration levels experienced by the top tray are significantly smaller than those produced by the trucks with significant attenuation of vibrations at frequencies above 20 Hz.
- However, the tray vibrations remain high in the 12 – 20 Hz region which further points to the existence of resonance within this frequency band and one possible cause of USB.

6 CONCLUSIONS AND RECOMMENDATIONS

This study has revealed that, when subjected to vertical vibration, the fruit, packed in trays, do respond by also vibrating resulting in relative, scuffing-like motion, between the fruit especially at resonant frequencies. Although not completely conclusive, it is very likely that it is this repeated inter-fruit scuffing or rubbing that initiates and precipitates the occurrence of under skin browning (USB).

Analysis of vibrations during transport show that the vehicles generate significant vibration intensity in the 12 – 20Hz band which corresponds to the measured resonant frequencies of the packed trays (measured for up to 4 layers). It is therefore likely that this sustained vibration over long periods (up to 70 Hrs) during the trip between Katherine, NT and Brisbane, Qld. Is the main cause of USB.

The level of USB observed in the field could not be reproduced under simulated conditions in the laboratory. This, it is supposed, is due primarily to the limited duration of the laboratory test (8 hours.)

Given their seasonal nature, the availability of fruit is intermittent. In addition, limitations associated with preserving the fruit for long durations make it difficult to obtain a large number of samples that can be preserved for a significant period. To that end, undertaking a thorough investigation with harvested fruit is difficult and impractical. Given that it has been established that the most likely cause if USB is mechanical - namely: the vibratory response of the packed fruit, the next step should involve studying the dynamic behaviour artificial replicas of fruit samples. This can be achieved by producing mechanically and geometrically identical fruits (using 3D scanning and printing technology). It may even be possible to imbed motion sensors (accelerometers and angular velocity sensors) within the artificial fruit thus making the monitoring of their motion less intrusive. This will also make the replica fruit easier to use in field trials. These replica fruit can then be packed in an identical manner as real fruits and submitted to controlled vibration excitation while their motion is measured and analysed. This approach can be used to develop and validate the effectiveness of various packaging / cushioning / lining designs aimed at reducing or elimination inter-fruit scuffing / rubbing.

NOTES

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Laboratory testing of pallet damping systems to reduce transport damage and under skin browning in ‘Honey Gold’ mango

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Hung van Duong, Andrew Macnish, Daryl Joyce, Peter Hofman, Pip Bryant

(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, the Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. The development of the disorder is associated with the combination of hot growing and harvest conditions, physical injury to the fruit, and low storage temperatures.

The physical damage associated with USB is typically thought to result from vibration during transportation by road freight. It was hypothesised that the use of foam pads within palletised stacks of trays may dampen vibration, potentially reducing fruit injury.

The current research used a vibration table to test the ability of foam pads to reduce the acceleration of fruit trays. Trials were also carried out to explore the relationship between frequency and resultant acceleration, and to examine the effects of tray position, weight and the use of strapping on acceleration.

Acceleration in weighted mango trays was found to peak at 7-10 Hz frequency, a range typically encountered in road freight. Acceleration was significantly higher in the top trays than in the bottom trays. The tested variety of foam types and rubber were ineffective in damping vibration and minimizing acceleration. In most cases, the foam layers added to the stacks significantly increased acceleration in the uppermost trays. However, strapping was shown to reduce acceleration in the top trays. The results of these trials suggest that the use of foam layers within pallets would not be effective in reducing physical damage to mangoes by vibration.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, and good shelf life. However, the variety is susceptible to underskin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results have consistently shown an association between physical damage to fruit and the development of USB symptoms. Under commercial operations physical injury resulting in USB typically occurs through vibration damage during road transport from packing sheds to distribution centres, over distances of 2000-3000 km. Rubbing of the fruit against tray liners, other fruit or tray edges are the primary causes of physical injury during transport, and USB commonly develops around these injury sites (Marques et al., 2011).

During transit, vibration is the greatest directly over axles, and vibration acceleration increases as it is transmitted through boxes or trays on a pallet (Thompson, 2007). Damage usually occurs to fruit in uppermost boxes near the rear of a trailer (Fischer, 1989; Hinsch et al., 1993; Thompson, 2007). Previous studies have shown that the peak of vertical acceleration often occurs in the 2.5-9 Hz range and that this range causes the most damage to the produce (Hinsch et al., 1993; Zhou et al., 2007). Vibration levels are dependent on the vehicle speed, road condition, packaging material and suspension type (Chonhenchob and Singh, 2003; Hinsch et al., 1993; Jarimopas et al., 2005). The present study aimed to test the hypothesis that vibration in the topmost trays may be reduced by placing foam pads within the stack. The objectives of this study were to: 1) measure acceleration in different tray positions up the stack at 6 Hz; 2) investigate vibration levels at various frequencies, and 3) compare vibration at different levels within the stack with foam pads inserted.

Materials and Methods

The experiments were conducted at the Postharvest Laboratory of the Maroochy Research Facility using a vibration table manufactured by Winsor and Son Pty Ltd., Australia. Mango trays of single layer fibre cardboard type with dimensions of 43 cm length x 36 cm width x 13 cm height were provided by Piñata

Farm Pty Ltd. A single stack of 15 trays was placed in the middle of the vibration table with lateral and vertical support from a metal frame. Each tray was weighted with a plastic bag containing 7 kg sand, equivalent to the typical weight of fruit per tray. Four additional trays of 7 kg sand were placed at each corner of the table to keep the table balanced (Figure 1). The heights of stack and table were 170 cm and 90 cm, respectively. A digital tachometer (Model TL 9936, JEM Tools) was used to determine the frequency of the table and the rotary regavolt was regulated to obtain the desired vibration table frequency. The maximum input volt was 110V.

Six vibration table trials were conducted.

Trial 1

Trial 1 measured acceleration levels at trays 2, 4, 6, 8, 10, 12, 14 and 15 up the stack. There were 8 runs operated at 6 Hz for this trial.

Trial 2

Trial 2 tested the effect of different thicknesses of ethylene vinyl acetate (EVA) foam on the vibration acceleration. The physical properties of EVA are shown in Table 1. The foam was placed underneath trays 1 (base) and 11 (middle). Acceleration was recorded at trays 2, 8, 12, and 15. There were two factors influencing acceleration tested in this trial; foam thickness at the middle: 0, 6, 12, 20 and 25 mm and, foam thickness at the base: 12, 20, and 25 mm. A total of 15 runs were made without strapping. To investigate the difference in acceleration with strapping, a strap was used to pull the top trays down tight against the metal frame as illustrated in Figure 1. This was to simulate the effect of the pallet wrapping reducing the potential movement of each tray. A total of 15 runs were made with strapping. All runs were conducted at 6 Hz.

Table 1. Physical properties of the polymer materials trialed for pallet damping.

Properties	Type									
	EVA-6	EVA-12	EVA-20	EVA-25	1	2	3	4	5	6
Material	Foam	Foam	Foam	Foam	Foam	Foam	Foam	Foam	Foam	Rubber
Density (kg/m ³)	30	30	30	30	29	16	19	26	29	-
Compression load (N)	9.77	5.92	6.25	9.36	0.65	0.30	0.54	0.72	1.03	100.7
Compression depth (mm)	3	6	10	12.5	5.5	6	5	5	14	2
Thickness (mm)	6	12	20	25	11	12	10	10	28	7
Modulus of elasticity (MPa)	0.195	0.118	0.125	0.187	0.013	0.006	0.011	0.014	0.021	3.523

Trial 3

Trial 3 tested the effect on acceleration of different foam types (1, 2, 3, 4, 5) and rubber placed in the middle of the stack, under tray 11. The materials tested are compared in Table 1. The vibration table was run at 6 Hz and acceleration was measured at trays 12 and 15

Trial 4

Trial 4 tested the effect of various frequencies of the vibration table on acceleration. No foam was used in this trial. Acceleration was recorded at trays 12 and 15. The relationship between input voltage and frequency is illustrated in Table 2.

Table 2. Relationship between input voltage and frequency

Input voltage (%)	29	37	46	54	62	70	76	85	95	103
Frequency (Hz)	3	4	5	6	7	8	9	10	11	12

Trial 5

Trial 5 tested the effect of the combination of various frequencies and foam types on acceleration. Runs were performed at frequencies of 3, 4, 5, 6, 8, 9 Hz, and three types of foam, namely 12 mm thickness EVA, type 5 foam and rubber were tested. Acceleration was recorded at trays 12 and 15.

In order to increase the area of contact surface between the trays, a 4 mm ply sheet was inserted under tray 11 beneath the foam or rubber pads for trials 2, 3 and 5.

Trial 6

Trial 6 tested the effect of three load weight on the vibration table on acceleration at 4, 7 and 10 Hz. The acceleration was recorded at a corner tray (Figure 1).

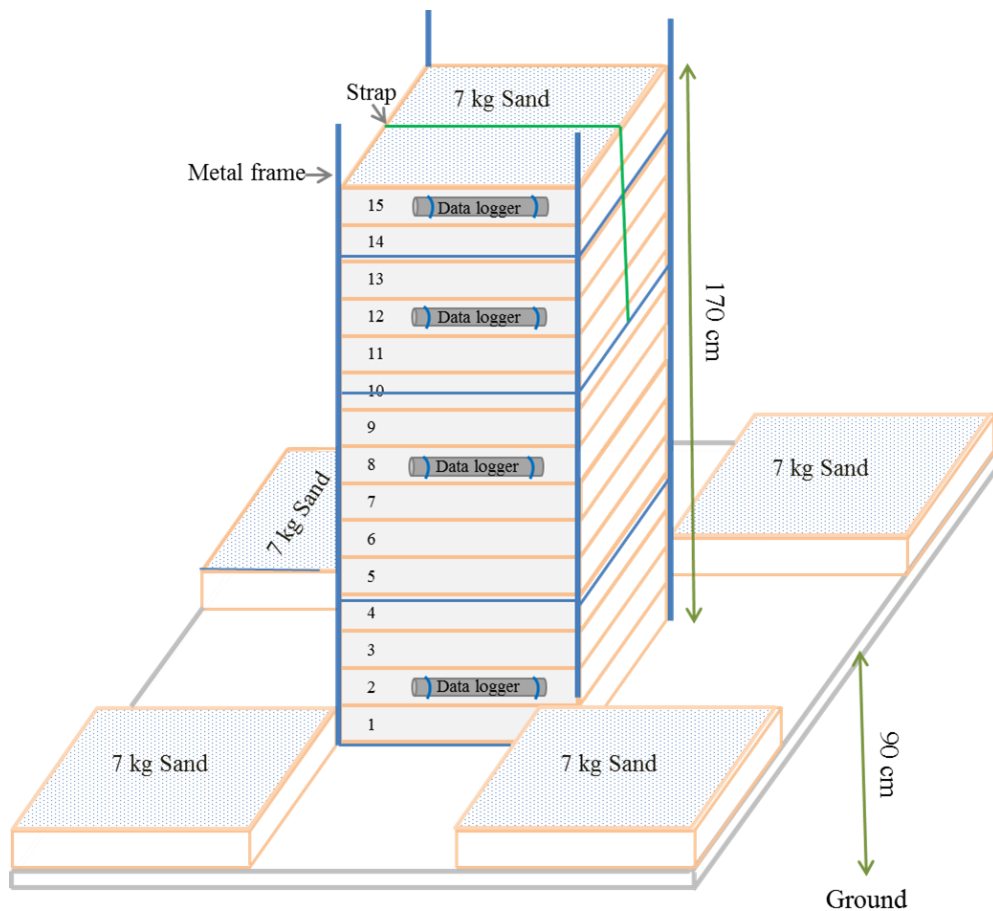


Figure 1. Arrangement of weighted trays, data loggers (accelerometers), frame and strapping on the vibration table.

Accelerometer

Accelerometers (Model MAT-1 Data Logger, Lowell Instruments LLC, USA) were attached horizontally to the external sides of the trays (Figure 2). Each accelerometer was attached to a 4 mm ply pad using two brackets, and this pad was then bolted onto the tray side, secured with another ply pad within the tray. Depending on the aim of each trial, the loggers were located at different tray positions as mentioned previously. The accelerometer was positioned as showed in Figure 1 and Figure 2 to measure acceleration in the vertical direction. The accelerometer was set at 16 Hz, 2 min and 2 s for burst rate, burst interval and burst duration, respectively, using MAT logger commander software. Using these settings, data was recorded every 2 min, for 2 s and 16 readings were collected in 1 s. Each run lasted 10 min and data from one 2 s sample (32 readings every 2 min) was averaged and used as one replicate. There were 5 replicates (each of 2 s duration) used within each run. The acceleration due to gravity (1 g) was subtracted from the data, and root mean square of acceleration was used for statistical analysis.

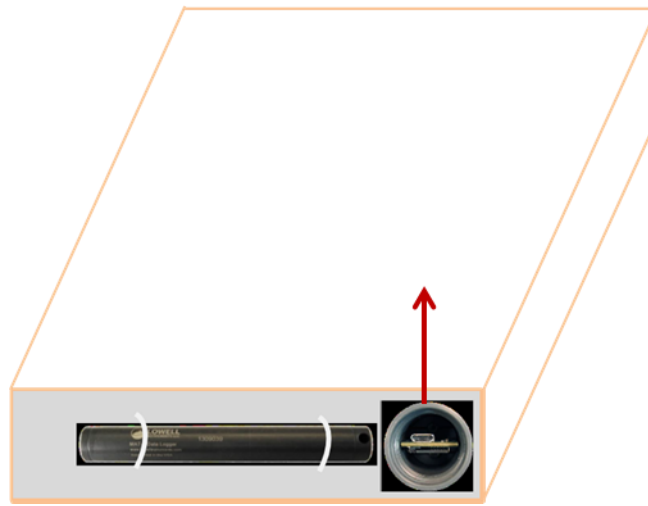


Figure 2. The orientation of the data logger. The logger was placed horizontally, with the mini USB port upward and flat.

Measuring modulus of elasticity for tested materials

Compression testing of materials was performed using an EZ test (Model EZ-SX, Shimadzu Corp, China). Samples of 100 mm² (10 mm width x 10 mm length) with different thicknesses (Table 1) were prepared. Three samples were prepared for each type of material. A 22 mm diameter cylindrical probe descended toward the sample at crosshead speed of 10 mm/min until 50% deformation. The maximum value of force was recorded and expressed in Newtons (N). Modulus of elasticity was calculated using equation (1) and the parameters provided in Table 2.

$$E = \frac{\sigma}{\varepsilon} \quad (1) \quad \sigma = \frac{F}{A} \quad (2) \quad \varepsilon = \frac{\Delta l}{l_0} \quad (3)$$

where E is modulus of elasticity (MPa), σ is stress (N/mm²), F is compression load (N),

A is cross area (mm²), ε is strain (-), Δl is compression depth (mm), l_0 is sample thickness (mm).

Statistical analysis

Data analyses were performed using GenStat® (Version 16.1, VSN International Ltd). One-way ANOVA and LSD comparison at 95 % level were conducted for trial 1, while two-way ANOVA was used in trials 2, 3, 4 and 5.

Results and discussion

Trial 1

Figure 3 shows the typical vertical acceleration measured in 1 s from different tray positions within the stack in trial 1. The results indicate that the frequency recorded from the accelerometer was the same as measured on the vibration table platform (6 Hz) and that acceleration displacement in the top trays was higher than that in the bottom trays. In addition, there was a significant difference ($P<0.05$) in acceleration recorded from the trays (Figure 4). It is clear that the acceleration was higher at higher locations in the stack and maximum acceleration was found with the top trays (12, 14 and 15). Relatively lower acceleration at tray 10 could be due to tray 10 being adjacent to a horizontal bar of the metal support frame. The higher acceleration measured in the top trays in the current trial is in agreement with previous findings by Fischer (1989) and Thompson (2007).

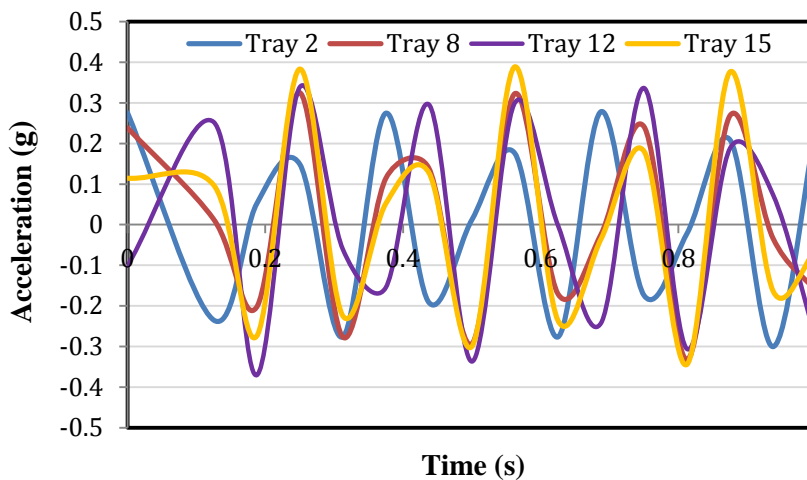


Figure 3. Typical vertical acceleration at 6 Hz over a one second period in different tray levels within the stack, where tray 1 = bottom and tray 15 = top of the stack.

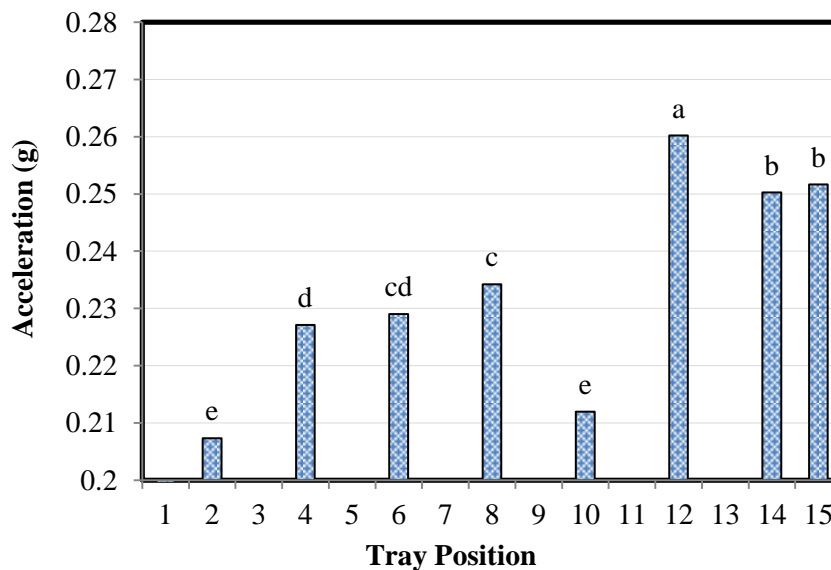


Figure 4. Average vertical acceleration at 6 Hz from bottom tray (1) to top tray (15) of the stack. Means (bars) with the same letters above are not significantly different at $P=0.05$ ($n=5$).

Trial 2

Figure 5 shows that EVA foam of varying thickness placed under tray 11 did not affect the acceleration at tray 2, but EVA of 6, 12 and 20 mm thickness increased acceleration in tray 8. All EVA foam pads inserted under tray 11 with foam at the base increased the acceleration at tray 12 and 15 (Figure 5). Although the elasticity of EVA of various thicknesses was different, no relationship was found between the increase in acceleration and modulus of elasticity. The combination of foam pads at the base and under tray 11 was ineffective in reducing acceleration regardless of strapping (Figure 6; Figure 7). However, strapping to reduce top tray movement helped to reduce the acceleration at tray 12 and 15 (Figure 8).

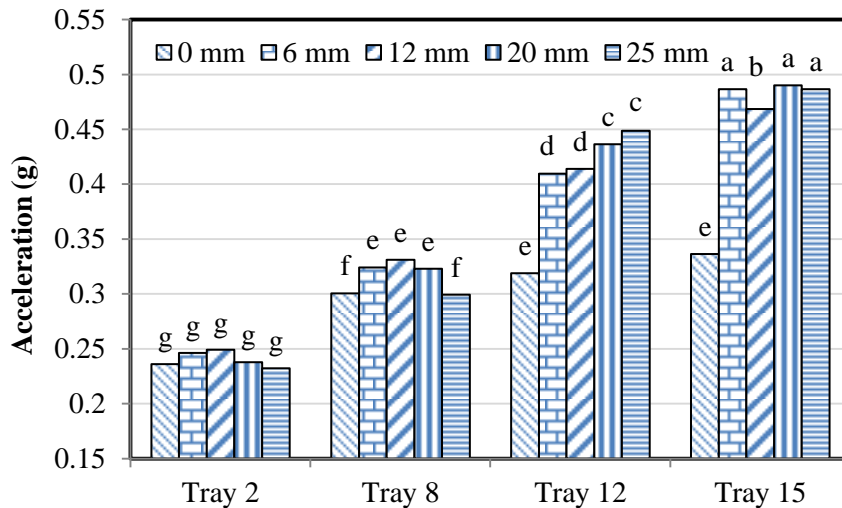


Figure 5. Acceleration at various tray levels (where 1=bottom and 15= top) with EVA foam (of thickness 6, 12, 20 or 25 mm) under tray 11, without strapping. Data were averaged across various foam treatments (12, 20 and 25 mm) at the base (under tray 1). Means (bars) with the same letters above are not significantly different at $P=0.05$ ($n=15$).

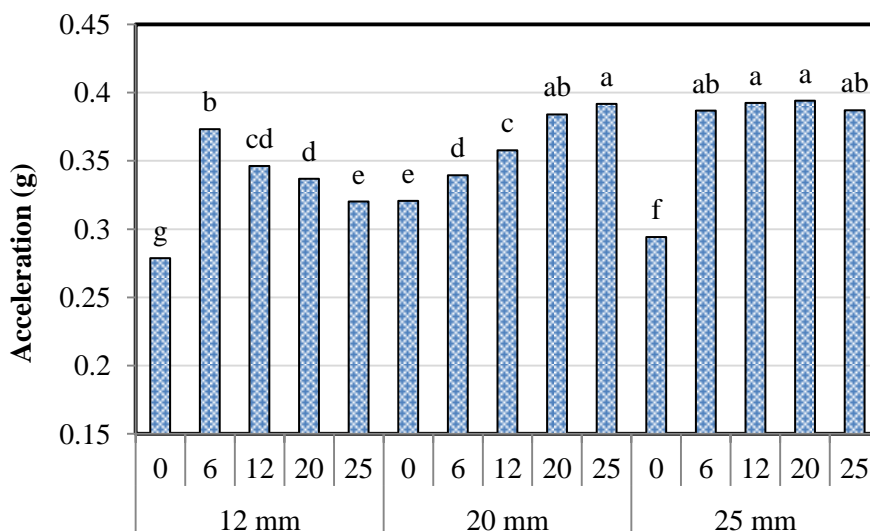


Figure 6. Average acceleration of trays treated by foam pads placed at base of the stack (of 12, 20 or 25 mm thickness) and under tray 11 (of 0, 6, 12, 20 or 25 mm thickness), without strapping. Data were averaged across all acceleration values at trays 2, 8, 12 and 15. Means (bars) with the same letter above are not significantly different at $P<0.05$ ($n=20$).

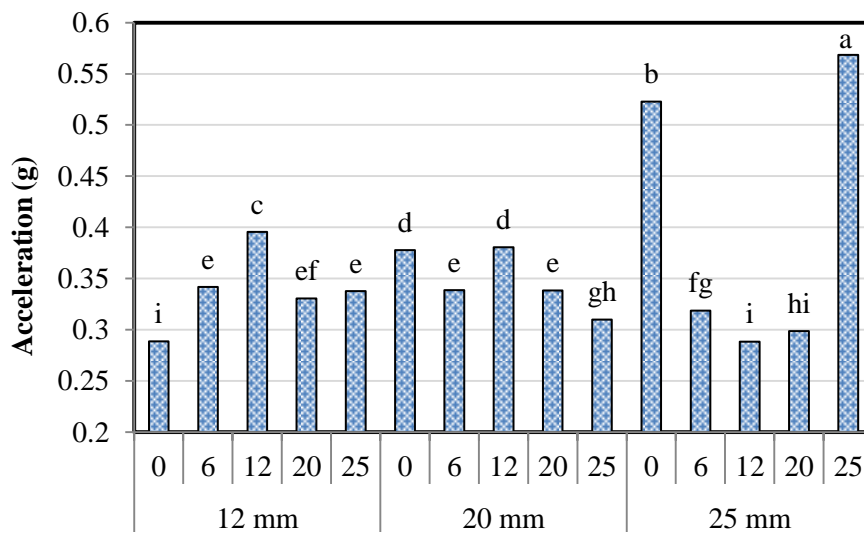


Figure 7. Average acceleration of trays treated by foam pads placed at base of the stack (of 12, 20 or 25 mm thickness) and under tray 11 (of 0, 6, 12, 20 or 25 mm thickness), with strapping. Data were averaged across all acceleration values at trays 2, 8, 12 and 15. Means (bars) with the same letter above are not significantly different at $P < 0.05$ ($n=20$).

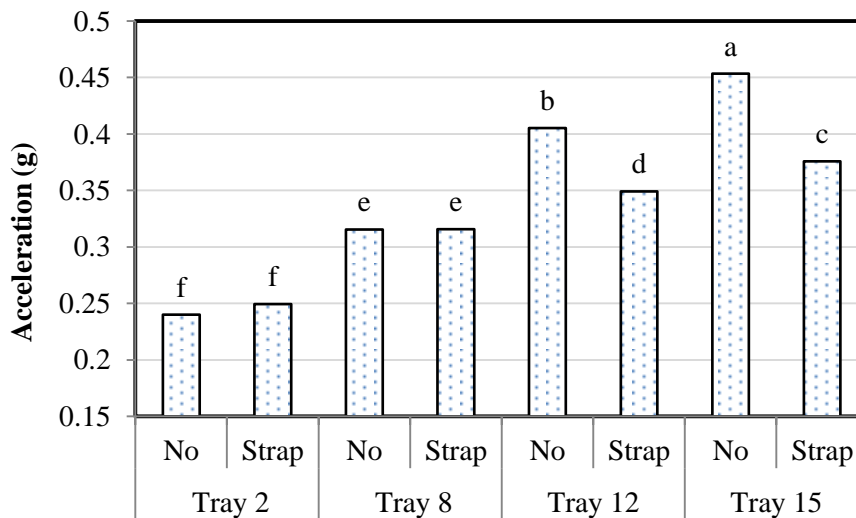


Figure 8. Average acceleration of trays (where tray 1 = bottom and tray 15 = top) with and without strapping. Data were averaged across all acceleration values with foam of various thicknesses at base (under tray 1) and under tray 11. Means (bars) with the same letter above are not significantly different at $P < 0.05$ ($n=75$).

Trial 3

Acceleration increased significantly ($P < 0.05$) when foam or rubber pads were placed under tray 11, except for 12 mm EVA (Figure 9). It seems that 12 mm EVA foam, which had higher elasticity than other foam types, did not affect acceleration. Rubber, with very high elasticity, and the most firm cushioning

tested, did not increase acceleration to the same extent as the other softer foams (types 1 to 5). The elasticity of type 1 and type 5 foam were almost the same (Table 1), but type 1 caused more acceleration at tray 15 than type 5. The variation in acceleration between the different materials did not appear to be clearly related to any of the physical properties shown in Table 1.

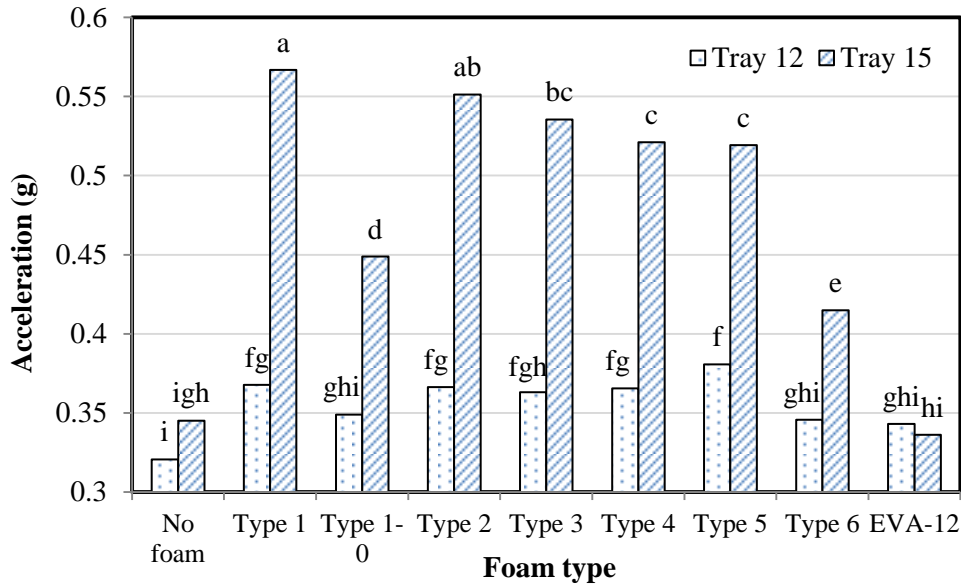


Figure 9. Acceleration at 6Hz in tray 12 and 15 (where tray 1=bottom and tray 15=top of stack) with various foam types placed under tray 11. Type 1-0 used type 1 foam but without a 4 mm ply sheet placed under the foam. Means (bars) with the same letters above are not significantly different at $P=0.05$ ($n=5$).

Trial 4

Figure 10 shows the change in acceleration over a range of frequencies. Tray position (at tray 12 or 15) did not affect acceleration ($P=0.62$). However, a significant increase in acceleration ($P<0.05$) was found in the 7-10 Hz range. Acceleration decreased when frequency was increased to 11 and 12 Hz, resulting in similar acceleration to that shown at 6 Hz. This result is in agreement with previous studies, which showed a peak in vertical acceleration often occurring in the 2.5-9 Hz range (Hinsch et al., 1993; Zhou et al., 2007).

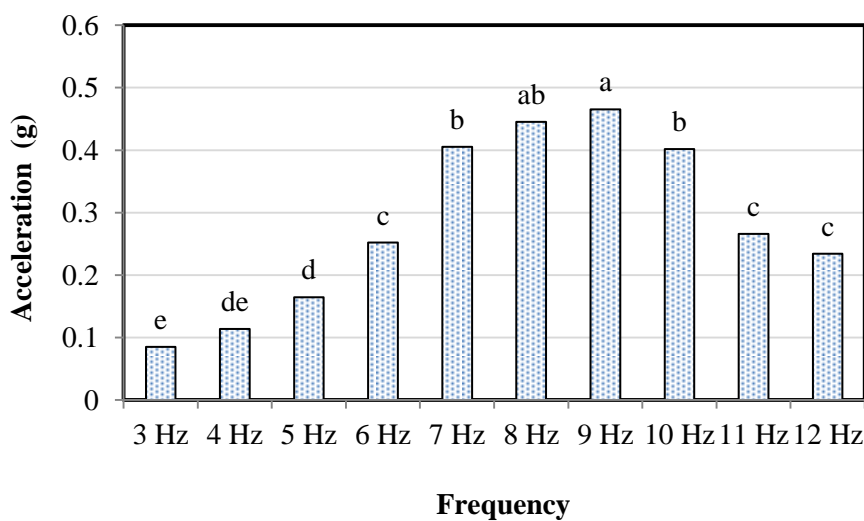


Figure 10. Change in acceleration with frequency. Data were averaged across all acceleration values at tray 12 and 15. Means (bars) with the same letter above are not significantly different at $P<0.05$ ($n=10$).

Trial 5

Figure 11 shows the change in acceleration over a range of frequencies and foam types placed under tray 11. There was no effect of foam type on acceleration at lower frequencies of 3, 4 and 5 Hz. The effect of foam on acceleration was inconsistent at higher frequency. For instance, 12 mm EVA and rubber significantly reduced acceleration compared to type 5 and no foam at 7 Hz, but they caused more acceleration at 8 Hz.

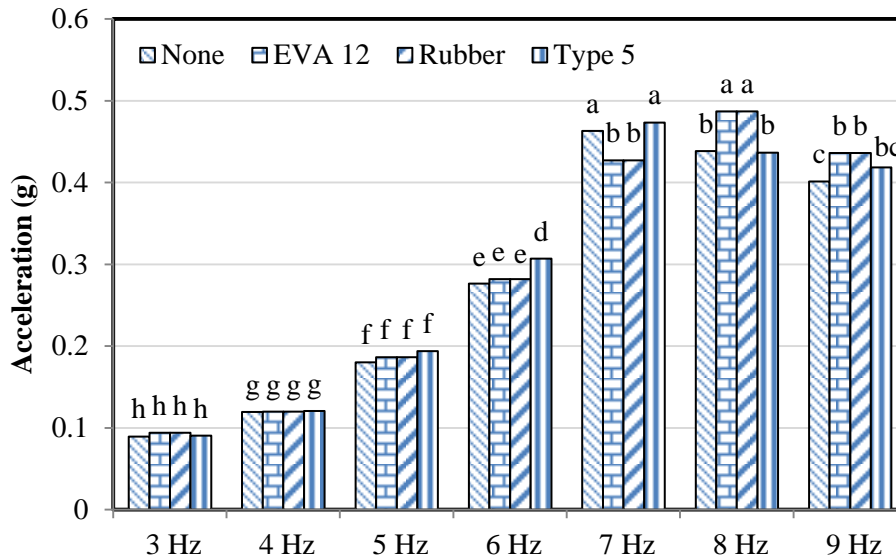


Figure 11. Change in acceleration over a range of frequencies, with various foam types placed under tray 11. Data were averaged across all acceleration values at tray 12 and 15. Means (bars) with the same letter above are not significantly different at $P < 0.05$ ($n = 10$).

Trial 6

Table 3 shows the effect of load weight on acceleration at three various frequencies of 4, 7 and 10 Hz (round per second) which converted from rotation (rpm). Obviously, acceleration was influenced by both frequencies and load weight. With the same load exerted on the table, the higher frequency resulted in the higher acceleration. In contrast, the higher load exerting on the table caused the less the acceleration at the same frequency.

Table 3. Effect of load weight on acceleration at three different frequencies.

Load (No. of 7 kg trays)	Voltage (%)	Rotation (rpm)	Acceleration (g)
19 (133 kg)	35	228	0.097
	62	428	0.253
	86	605	0.620
9 (63 kg)	35	243	0.144
	62	452	0.387
	86	637	0.621
4 (28 kg)	35	235	0.389
	62	456	0.466
	86	622	0.700



Conclusions

Some initial conclusions are drawn as follows:

- Acceleration measured in the top trays was significantly higher than that in the bottom trays.
- Strapping reduced acceleration in the top trays.
- An increase in frequency did not result in an increase in acceleration. The greatest acceleration was found in the 7-10 Hz range.
- The tested foams and rubber were ineffective in minimizing acceleration in the top trays.
- The effect of the materials tested on acceleration could not be explained solely by the measured physical properties of the material, such as modulus of elasticity.
- The acceleration was affected by both frequency and load weight exerted on the table.

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Testing of pallet damping systems in commercial refrigerated transport

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Hung van Duong, Pip Bryant, Peter Hofman, Ted Winston,
Gavin Scurr

(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, the Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. The development of the disorder is associated with the combination of hot growing and harvest conditions, physical injury to the fruit, and low storage temperatures.

The physical damage associated with USB is typically thought to result from vibration during transportation by road freight. It was hypothesised that the use of foam pads within palletised stacks of trays may dampen vibration, potentially reducing fruit injury.

In previous research using a vibration table, foam layers placed within the pallet stack did not reduce vibration, and in some cases increased acceleration in the uppermost trays. However, it was thought that the conditions during road freight may differ substantially from the vibration table simulation, potentially leading to different responses. To test the effect of foam pallet damping under commercial conditions, foam layers were placed within pallets of mangoes, and the pallets were transported by road freight from the Katherine region of the Northern Territory to south-east Queensland. The fruit were then ripened and assessed for USB and signs of physical damage.

The commercial trial confirmed that foam inserts within the pallet did not significantly reduce damage. In some cases, USB was significantly increased by the addition of the foam layer. More research is required, perhaps testing the suitability of non-Newtonian materials, where the viscosity increases with increased stress.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Previous research has shown a strong association between USB and physical damage to the fruit. Under commercial operations physical damage appears to occur most commonly through vibration during road transport. Rubbing of the fruit against tray liners, other fruit or tray edges are the primary causes of physical injury during transport, and USB commonly develops around these injury sites (Marques et al., 2011). The disorder is usually most severe in fruit transported from the Northern Territory to southern markets, transported by road freight over distances of 2000-3000 km.

During transit, vibration is the greatest directly over the rear axles, and vibration acceleration increases as it is transmitted through boxes or trays on a pallet (Thompson, 2007). Damage usually occurs to fruit in uppermost boxes near the rear of a trailer (Fischer, 1989; Hinsch et al., 1993; Thompson, 2007). Previous studies have shown that the peak of vertical acceleration often occurs in the 2.5-9 Hz range and that this range causes the most damage to the produce (Hinsch et al., 1993; Zhou et al., 2007). Vibration levels are dependent on the vehicle speed, road condition, packaging material and suspension type (Chonhenchob and Singh, 2003; Hinsch et al., 1993; Jarimopas et al., 2005).

Previous laboratory-based trials using a vibration table generating about 6 Hz (6 vibrations per second), indicated that the top 4-5 layers of the pallet were subjected to the strongest acceleration. The addition of foam layers within the pallet stack, of varying composition and thickness, showed little benefit in reducing acceleration, and often increased the vibration movement up the stack. However, it is likely that the relatively consistent frequency generated by the vibration table is very different to the vibrations experienced under commercial transport conditions from the Northern Territory to southern markets. Under road transport, vibration is semi-random, although often comprised of a few predominant frequencies, with the addition of irregular jolts and bumps from the road surface (Hilton, 1994), resulting in potentially very different conditions to those simulated on the vibration table.

The present study aimed to test the hypothesis that vibration in the topmost trays may be reduced by placing foam pads within the stack. Three different types of 10-12 mm foam were placed within pallet stacks to determine the potential for these treatments to reduce vibration damage in commercial consignments.

Materials and Methods

The 4 foam treatments (Table 1) were applied to pallets being transported commercially from Fox Road in the Katherine region of the Northern Territory (NT).

Table 1: Mechanical properties of foam treatments placed within pallets transported by road freight from the Northern Territory to south-east Queensland. The foam was compressed using a 12 mm spherical probe, and the force (Newtons) required to compress the foam to half its normal thickness was recorded. The modulus of elasticity was calculated as described below (Equation 1).

Treatment	Foam properties				
	Thickness (mm)	Density (kg/m ³)	Compressive load required to deform 50% (N)	Depth of 50% compression (mm)	Modulus of elasticity (MPa)
Control	-	-	-	-	-
EVA-12	12	30	5.92	6	0.118
White foam	12	16	0.30	6	0.006
Green foam	10	19	0.54	5	0.011

The foam layers were placed into 3 separate pallets, 4 layers from the top. Five standard cardboard pallet sheets were taped together with the corrugations in the sheet running at right angles for each sheet. The foam was taped to the sheets to provide a stable base for the foam. The top 3 layers of fruit in the pallet had a foam insert placed over the top of the tray to reduce transport damage to the fruit in the upper layers.

On each treated pallet, 2 vibration loggers were used, a Definium logger and MAT-1 logger (Model MAT-1 Data Logger, Lowell Instruments LLC, USA). The 2 loggers were secured to the opposing long sides of a tray, with fruit removed to allow the loggers to be screwed securely to the sides. Vibration loggers were located in the third layer from the top of the pallet, on the right corner, as viewed from the container door, and were oriented parallel to the door. The Definium logger was attached with the GPS antenna connection uppermost. The MAT-1 logger was set to record at 32 Hz with continuous reading. The pallets were placed over the rear axle of a commercial 20 pallet trailer and were transported from Fox Road to Wamuran, south-east Queensland (SEQ).

Measuring modulus of elasticity for tested materials

Compression testing of materials was performed using an EZ test (Model EZ-SX, Shimadzu Corp, China). Samples of 100 mm² (10 mm width x 10 mm length) with different thicknesses (Table 1) were prepared. Three samples were prepared for each type of material. A 22 mm diameter cylindrical probe descended toward the sample at a crosshead speed of 10 mm/min until the material had deformed to 50% thickness. The maximum value of force required to deform the foam to 50% thickness was recorded and expressed in Newtons (N). Modulus of elasticity was calculated using Equation 1 and the parameters provided in Table 1.

Equation 1:

$$E = \frac{\sigma}{\varepsilon} \quad (1) \quad \sigma = \frac{F}{A} \quad (2) \quad \varepsilon = \frac{\Delta l}{l_0} \quad (3)$$

where E is modulus of elasticity (MPa), σ is stress (N/mm²), F is compression load (N),
 A is cross area (mm²), ε is strain (-), Δl is compression depth (mm), l_0 is sample thickness (mm).

Quality assessment

At Wamuran, the fruit from the top 5 layers of the pallet (8 trays per layer) were ripened under normal commercial conditions. When near eating ripe, the fruit were visually assessed for USB and signs of rub marks or physical damage that had broken the skin, using the following scale:

- 0 = nil,
- 1 = <1 cm²,
- 2 = 1 to 3cm²,
- 3 = 3 to 12cm² (10%),
- 4 = >12cm² (10%) and <25%,
- 5 = >25%.

Statistical analysis

Data analyses were performed using GenStat® (Version 16.1, VSN International Ltd). The research was carried out as a preliminary trial, with each treatment applied to a single pallet. Two-way ANOVA and LSD comparison at 95% level were conducted to detect treatment/pallet differences, using tray averages as the experimental unit. For analysis of USB severity, scores were analysed only from fruit with the disorder, using a general ANOVA, with individual fruit as the experimental unit.

Results and discussion

The addition of foam layers within the pallets did not reduce damage to fruit, with the control fruit showing the lowest levels of damage (Table 2). White foam and EVA foam significantly increased the incidence and severity of USB damage, while green foam resulted in USB levels not significantly different to the control. Rub mark damage did not significantly differ between the foam treatments and control. Physical damage that had broken the skin of the fruit was observed, but the incidence was very low (around 1.2% of fruit), and no significant effects were observed due to treatment or tray layer (data not shown).

These results were in agreement with simulations carried out on a vibration table, where the addition of foam layers within the pallet did not reduce acceleration in the upper level trays, and in many cases increased the vibration moving up the stack. In the current trial, the white foam resulted in the highest USB and also had the lowest modulus of elasticity (Table 1).

It is possible that the increased levels of damage observed with the addition of foam layers into the pallet may result from the ability of the top trays to tilt further, with the compression of one side of the foam material. This could result in greater movement or swaying of the trays above the foam layer. The foam layers may also have resulted in more bouncing of the upper layers, leading to greater repetition of each vibration movement during transport.

Table 2: USB and rub mark damage shown in 'Honey Gold' mango fruit transported by commercial road freight from the Northern Territory to SE Queensland. Foam layers were inserted below the 4th row from the top of each pallet.

Treatment	Incidence of USB >1cm ² (% of fruit)	USB severity - average USB score of fruit with the disorder (1-5)	Rub mark incidence (% of fruit)
Control	12.5 ^c	1.9 ^c	18.5
EVA	24.2 ^b	2.1 ^{ab}	24.1
White foam	31.3 ^a	2.3 ^a	25.6
Green foam	14.0 ^c	1.9 ^{bc}	23.8
LSD	4.8	0.2	6.4
Sample size	40	112-297	40

The uppermost trays showed significantly more damage to fruit, with greater incidence of USB and rub mark damage (Table 3). These results were in line with the results observed using the vibration table trials, where acceleration was highest in the uppermost trays.

Table 3: Effect of row in the pallet on USB and rub mark damage on 'Honey Gold' mango transported by commercial road freight from the Northern Territory to SE Queensland. Foam layers were inserted below the 4th row from the top of each pallet. Layer 5 was below the foam layer.

Tray level (1=top of pallet)	Incidence of any USB (% of fruit)	Incidence of USB >1cm ² (% of fruit)	Rub mark incidence (% of fruit)	Rub mark score
1	41.7 ^a	25.4 ^a	41.7 ^a	0.43 ^a
2	34.2 ^b	20.0 ^{ab}	31.5 ^b	0.32 ^b
3	31.3 ^b	19.3 ^{bc}	17.7 ^c	0.18 ^c
4	35.1 ^{ab}	23.3 ^{ab}	9.9 ^d	0.10 ^d
5	23.8 ^c	14.5 ^c	14.1 ^{cd}	0.14 ^{cd}
LSD	7.2	5.4	7.2	0.07
Sample size	32	32	32	32

There was no significant interaction between foam treatment and tray layer.

The vibration data are presented in a separate report.

Conclusions


These results confirm the potential impact of pallet characteristics on USB, supposedly through vibration transmission from the road to the upper layers of the pallet. The foam treatments either had no effect or increased USB. Alternative damping systems should be evaluated in the laboratory prior to commercial trials.

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Can irrigation reduce USB on ‘Honey Gold’ mango?

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Peter Hofman, Ted Winston, Bhavisha Mehta, Daryl Joyce,
Philippa Bryant, Lindsay Hewitt, Gavin Scurr

(2014/15)

This publication has been compiled by Peter Hofman of AgriSciences Qld, Department of Agriculture and Fisheries.

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Summary

The 'Honey Gold' mango fruit is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. It occurs primarily in fruit grown in the hotter production areas, especially the Northern Territory. Previous research indicated that fruit harvested in the afternoon were significantly more susceptible to USB than those harvested at night or in the morning. Also, two farms in the Katherine area of the Northern Territory produced fruit with differing susceptibility to USB over several years. Irrigation was considered one of the possible causes of both the diurnal effects and differences between farms.

To test this hypothesis, several irrigation treatments were applied at Fox Road, the Katherine farm observed to produce more susceptible fruit. One management block was irrigated as per normal practice for the farm, which involved irrigation every 2nd night and a reduction in irrigation in the last 2-3 weeks before harvest, while a second management block was irrigated as above but with no reduction toward harvest. A third management block received 1 h irrigation 3 times per day, every day until harvest. The blocks were harvested under standard commercial conditions, with additional fruit sampled from trees and subjected to a standard USB abrasion test. The irrigation treatments were applied to whole management blocks.

The everyday irrigation treatment reduced the soil water potential as expected, and also reduced the decline in leaf stomatal conductance during the middle of the day. These results confirmed potentially less moisture stress on trees under the every day irrigation treatment. The total block yield increased by 16% with everyday irrigation compared to standard irrigation, and the percentage of fruit in the larger fruit size categories was higher. This effect was confirmed by counting fruit number per tree and estimating average fruit size per tree. However, the everyday irrigation treatment reduced the percentage of fruit in premium by about 6% compared with no reduction, although assessment of fruit on the tree indicated a lower percentage of reject fruit from sunburn and misshapen fruit from excess heat.

The USB abrasion test did not confirm an effect of irrigation on fruit susceptibility to USB. However, the tree and packhouse data suggested a potential yield and fruit size benefit from increased irrigation, which justifies further investigation.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, small seed size and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results over the last three seasons have consistently found that Honey Gold mango fruit from Dean's farm in Katherine are less susceptible to USB following abrasion, compared with fruit from Fox Road farm. These farms are about 15 km distant. One of the possible causal mechanisms is that less irrigation and more sandy soils at Fox Road increases tree and fruit water stress. This may contribute to the higher USB susceptibility of fruit harvested between 2-6 pm.

The results from the 2012/13 season indicate that one of the causes for more USB in afternoon-harvested fruit is more "aggressive" sap from these fruit. Increased irrigation may reduce water stress on the afternoon fruit, thereby diluting the harmful components in the sap.

This trial investigated whether increased irrigation scheduling at Fox Road could increase the resistance of Honey Gold fruit to USB. The treatments are based on the assumption that most water uptake occurs within the top 30 cm of the soil profile, and that more frequent irrigation, and probably during the day, is more likely to reduce tree water stress.

Materials and Methods

Treatments

The trial was conducted at the Piñata farm at Fox Road, Katherine. The treatments were applied to whole irrigation blocks (valves), with trees on all the treatment blocks of the same age. Soil type was very uniform across all blocks (deep sand). All trees had one sprinkler per tree delivering 94 L per hour. All water was from on-farm bores. The treatments are described in **Table 1**.

Table 1: Irrigation treatments applied to 'Honey Gold' mango blocks on the Piñata Fox Road farm.

Treatment	Valve (block)	Irrigation frequency	Hours per irrigation	Timing of irrigation	L/week	2-3 wks before harvest
1 Standard	26	Every 2 d	2 ¹	Night	658	Reduce irrigation ²
2 Every day	24	Every day	1	1 h at each of 10 am, 2 pm and 10 pm	1974	No reduction
3 Standard no reduction	22	Every 2 d	2	Night	658	No reduction

¹1.5 hrs for the first 3 weeks because tensiometer readings indicated saturation. Irrigation then increased to 2 hrs

²Typical reduction is from 1.5 h every 2nd day from 3wks before harvest, to 1 h from 2 wks, then 30 min from 1 wk

The irrigation treatments started several days after the commencement of normal irrigation, close to the start of flowering (about 18/7/2015). Current standard commercial practice (first treatment) involved reducing irrigation 2-3 weeks before expected harvest to enhance maturity. All other treatments received full irrigation up to harvest.

Within each block/treatment, three adjacent rows were selected as replicated sampling areas in each irrigation block, and 10 trees selected in each of these sampling areas. All measurements were carried out on these 10 trees in each of the three replicate rows per treatment.

Soil responses

Tensiometers were installed at tree 1 and tree 10 of the 10 trees that were selected for sampling. One tensiometer was installed at 30 cm depth and one at 60 cm depth on each of the above trees for each treatment (two tensiometers of each depth per treatment). They were placed within the wetting zone of the sprinklers and in the drip zone of the tree canopy at 50 cm from the trunk and not in the shadow of the sprinklers.

The tensiometers were filled with good quality water to which algacide had been added, then sealed with a new serum stopper. They were left in a bucket of water for one day and the tips kept wet until installation. A hole was made to the required depth with an auger. A soil slurry was made from the soil obtained from the hole, the slurry carefully dropped into the hole and the tensiometer pushed into the slurry so that the whole ceramic cup was covered, then twisted in to ensure a good contact between the slurry and the tensiometer cup. The rest of the hole was filled with friable soil and watered. Any part protruding more than 10 cm from the soil was covered with aluminium foil. The tensiometers were allowed to settle for a few days then the soil potential recorded before 8 am every 2-4 days.

The wetting pattern of the soil was observed at about 2 pm on the day before harvest by digging a small pit to about 60 cm in a similar position under the canopy as the tensiometer placement. The wetness appearance of the soil was noted.

Tree responses to irrigation treatments

The stomatal conductance of the leaves was measured with a steady state porometer (Decagon Devices, SC-1 Leaf Porometer) on the day of harvest, three times during the day. For each of the 10 trees in each of the three replicate rows per treatment, three fully expanded leaves per tree adjacent to fruit were selected at about 1.5 m height, and clearly marked (30 leaves per treatment).

Tree yield and fruit defects

On five of the tagged trees per sampled row, the total fruit number was recorded, and the average fruit weight calculated by recording the combined weight of 50 average sized fruit per tree. Treatment effects on sunburn and fruit shape were estimated by counting the number of fruit per tree with brown/black sunburn of more than 1 cm², and the number of misshapen fruit due to excess sun exposure.

Commercial trial

All treatments were harvested between 2-4 pm on 19/11/14 using standard commercial practices. To minimize time-of-day effects, one harvest aid team harvested the first replication of treatment one, another harvest aid harvested replication one of treatment two etc. When the first replication of all treatments had been harvested, the harvest aid on treatment one was moved to replication two of treatment two, and so on to minimize harvest aid team/treatment interactions. Two bins per replication were harvested and the bin numbers for each replication/treatment recorded. The bins were transported to the holding shed on farm within 30 min of harvest and were transported to the packhouse the following day.

The fruit were packed over a commercial packline under standard conditions. The two bins per replication were placed on the line together and 10 trays of count 14 collected after packing. The trays were randomized on one pallet, with a tray from the first replication of all treatments placed on the pallet first, then another tray of each of the replications, and so on. A hobo temperature logger was placed in the third row from the top and the pallet placed in a cold room in the packhouse set at 12°C. The fruit were held in the coldroom for about 6 d then placed near the back axle in a 10.5 m refrigerated trailer at 14°C for road freight from Katherine to Wamuran (south east Queensland) .

Data were obtained from the packhouse on quality grade (premium, 1st class, bulks and juice) and the kg of fruit in each count (the number of fruit in a 7 kg tray) for each of the treatment blocks.

USB abrasion test

Two typical fruit per tree from the 10 marked trees (total of 20 fruit) per row/replication were harvested between 2-4 pm on the same day as the commercial trial and the fruit labelled. The fruit were then abraded at four locations around the largest circumference of the fruit using a small orbital finishing Sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial 12°C-set cold room for at least 6 d, then placed on a pallet near the rear of a 10.5 m standard road trailer, and transported to Wamuran at a set temperature of about 14°C.

The fruit were ripened at about 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion and of the USB lesion (including the abraded area) were measured separately, and the area of each calculated using the formula for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Where required the areas were converted to a rating score of:

- 0 = nil,
- 1 = up to 1 cm²,
- 2 = 1 to 3cm²,
- 3 = 3 to 12cm²,
- 4 = >12cm² (10%) and <25%,
- 5 = >25% of the fruit surface area affected.

USB was also observed on areas of the fruit that were not abraded with sandpaper. These were assumed to have been caused by normal commercial practices from packing onwards. These USB areas were also calculated as above.

Statistical analysis

This trial was designed as an exploratory trial, with the intention of repeating in following seasons assuming promising results. Due to the practical limitations of applying irrigation treatments, treatments were applied to whole blocks, and replication in a single season was not possible. Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), with the 'General Analysis of Variance' model used to analyse the data, to give a preliminary indication of treatment/block differences. The least significant difference (LSD) procedure at $P = 0.05$ was used to test for differences between treatment/block means.

Results and discussion

Fruit temperatures

Fruit pulp temperatures were maintained between 14-16°C for about 5 d before transport, then at 13-16°C during transport (Figure 1).

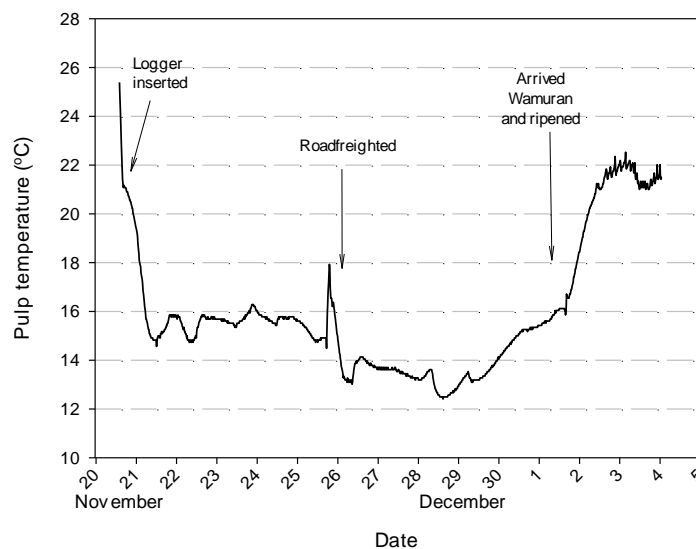


Figure 1: Fruit temperatures following the USB test, and during road freight to Wamuran (south east Queensland)

Soil and tree water status

Soil moisture potential was more negative at 60 vs 30 cm depth as expected (**Table 2** and **Figure 2**). Irrigation every day resulted in less negative water potential than the other treatments, suggesting increased water availability to the trees. This was observed across the fruit growth period and in the last two weeks before harvest.

Table 1: Soil water potential at 30 and 60 cm depth in the drip zone of 'Honey Gold' mango trees receiving irrigation every second day then reducing during the last 2 weeks before harvest (standard) or irrigation every day, or standard irrigation but with no reduction toward harvest. The data (recorded every 2-4 d) are averaged from flowering to harvest, or during the last two weeks before harvest. Means within each column with the same letter are not statistically different (P=0.05).

Treatment	Soil water potential (mPa)			
	From flowering to harvest		Final 2 weeks	
	30 cm depth	60 cm	30 cm	60 cm
Standard	-7.1 ^b	-14.0 ^a	-8.5 ^a	-12.0 ^b
Every day	-5.9 ^c	-9.1 ^c	-6.1 ^b	-9.6 ^c
Standard with no reduction	-8.2 ^a	-12.1 ^b	-9.6 ^a	-14.4 ^a

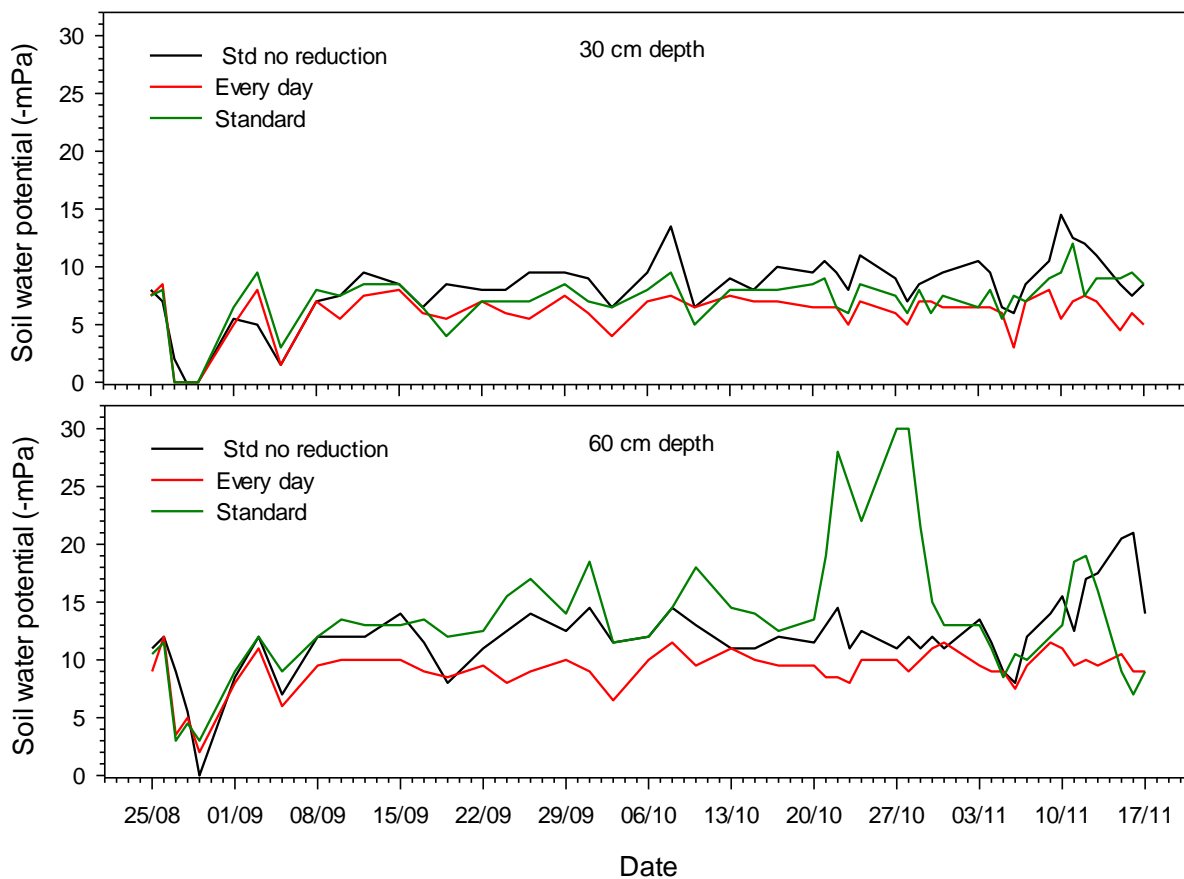


Figure 2: Soil tensiometer (- mPa) from flowering to harvest. The high readings at 60 cm in late October were the result of high readings in one tensiometer.

Leaf stomatal conductance increased from early morning to midday in all treatments (**Figure 3**). The higher conductance in the every day irrigation treatment implies less tree water stress, which is in line with the less negative soil water potential in this treatment compared with the others.

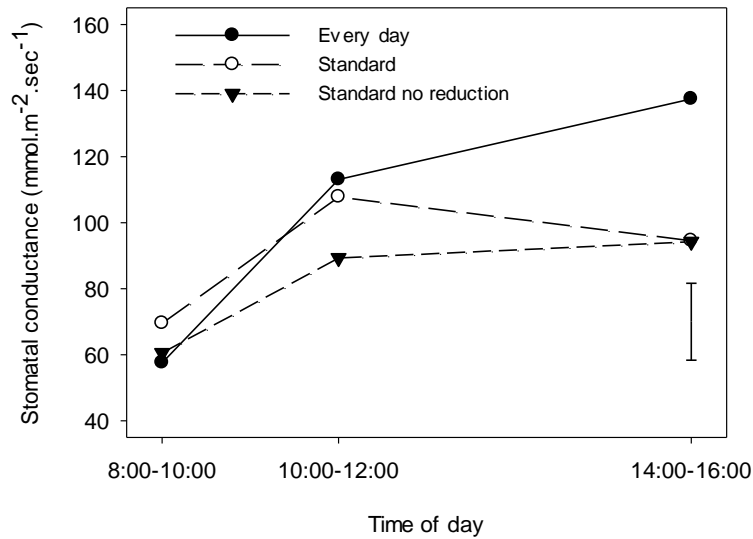


Figure 3: Stomatal conductance of ‘Honey Gold’ mango tree leaves at several times during the day of harvest. The trees received irrigation every second day, with reduced irrigation during the last 2 weeks before harvest (standard) or irrigation every day, or standard irrigation but with no reduction toward harvest. Treatment means that are greater than the vertical bar indicate statistically significant treatment differences at P=0.05.

Tree yield and fruit downgrade

Fruit number per tree was the lowest with standard irrigation, while average fruit weight was the highest with irrigation every day (**Table 2**). Every day irrigation resulted in 36 kg fruit yield per tree compared with 30-32 kg per tree for the standard treatments, which equates to a 20% increase in yield compared with standard irrigation. In addition, every day irrigation reduced the percentage of deformed fruit due to excess sun exposure and the percentage of fruit not suitable for the fresh market.

Table 2: Effect of irrigation treatment on fruit number per tree, fruit weight, percent dry matter, and percentage of fruit with black sunburn, deformed fruit from excess sun exposure and total reject fruit (black sunburn plus deformed). Means within each column with the same letter are not statistically different (P=0.05).

Treatment	Fruit count per tree	Fruit weight (g)	%DM	% of fruit with black sunburn	% deformed fruit	% reject fruit
Standard	60.8 ^b	494.8 ^{ab}	17.5 ^a	0.3	6.0 ^a	6.3 ^a
Every day	70.7 ^a	511.3 ^a	15.5 ^b	0.3	1.9 ^b	2.2 ^b
Standard, no reduction	67.7 ^a	478.0 ^b	17.4 ^a	0.9	5.9 ^a	6.7 ^a

Commercial trial

The commercial packout data from the packhouse indicated that every day irrigation increased total yield by about 16% compared with standard irrigation. This is similar to the increase estimated from fruit counts per tree (see above). In addition, the every day and no reduction treatments reduced the percentage of fruit in counts 14-18 (smaller fruit categories) and increased the percentage of fruit in counts 10-12 compared with standard irrigation (**Figure 4**). Therefore, part of the yield increase with every day and no reduction irrigation was through increased average fruit size.

Every day irrigation reduced the % packouts in the premium grade (**Table 3**). This does not support the estimation that this treatment reduced the percentage of reject fruit based on black sunburn and deformed fruit observed on the tree.

Table 3: Effect of irrigation treatment on commercial packout data from the packhouse, both as the total weight (kg) per grade, and the % of fruit in each grade.

Irrigation treatment	Premium	Class 1	Bulk	Juice	Total
Kg per class					
Standard	19,411	8,463	2,370	1,102	31,346
Every day	20,475	11,046	3,975	1,110	36,606
No reduction	455	406	375	406	1,642
% in each grade					
Standard	62	27	8	4	
Every day	56	30	11	3	
No reduction	28	25	23	25	

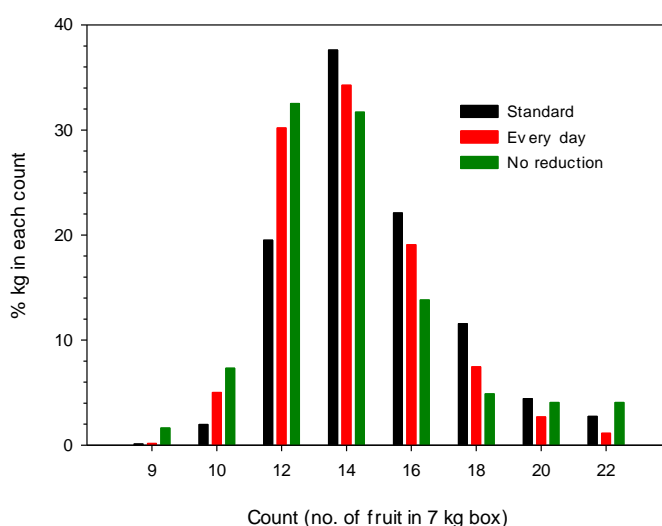


Figure 4: The effect of irrigation on the percentage of the total weight (kg) in each count (the number of fruit in each 7 kg tray). The data are from the packout records from the packhouse.

No USB results on arrival at Wamuran were available from the commercial trial because it was too difficult to select the packed trays from each of the bins/treatments under the pressure of a heavy packing schedule.

USB abrasion test

Irrigation had little effect on USB severity around the abrasion points (**Table 44**). However, the percentage of fruit with greater than 1 cm² USB was significantly less when there was no reduction in irrigation towards the end of harvest.

Combined, these results suggest that more frequent irrigation could increase yield, reduce the percentage of rejected fruit from excess sun exposure, and possibly increase resistance to USB. This trial did not include treatment replication because of the complexity of applying fully replicated irrigation trials. However, based on the promising results this season, the trial will be repeated next season to provide replication across seasons and to confirm the robustness of these results.

Mango sap samples were taken during this trial in order to explain any possible treatment effects on USB. The sap samples are still being analysed and will be presented in subsequent reports.

Table 4: Effect of various irrigation treatments on USB severity and the percentage of fruit with USB greater than 1 cm². Means within each column with the same letter are not statistically different (P=0.05).

Treatment	USB severity (0-5)		% of fruit with >1 cm ² USB	
	At abrasion sites	In non-abrasion areas	At abrasion sites	In non-abrasion areas
Standard	3.7	0.31	16.7 ^a	11.5
Every day	3.5	0.49	11.5 ^{ab}	16.7
Standard with no reduction	3.4	0.26	3.9 ^b	9.0

Irrigation effects on USB of 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Pip Bryant, Gavin Scurr

(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest, subsequent low temperature storage and vibration damage in transport.

USB susceptibility is consistently higher in fruit harvested during the hotter times of the day, when trees and fruit are likely to be under the most water stress. It was hypothesised that reducing water stress by increased rates of irrigation could lessen USB. In the 2014/15 season 3 irrigation treatments were applied to blocks at Fox Road, in the Katherine region of the Northern Territory. The increased irrigation treatments did not appear to reduce USB, but showed potential benefits in increased yield and reduced fruit defects caused by sun exposure.

The current study aimed to confirm the benefits shown in the previous season, and to study additional irrigation regimes. In the 2015/16 season 5 irrigation regimes were applied to whole management blocks. The standard irrigation treatment was applied for 2 hours every second night. Alternative treatments were applied for 1 h duration twice each day, and 1 h duration 3 times each day. In addition, high-low and low-high treatments compared increasing the irrigation rate to the 3 per day regime either early or late in fruit development.

Increased irrigation resulted in higher soil moisture content, particularly in the top of the soil profile, and greater stomatal conductance, suggesting reduced tree moisture stress during the middle of the day. The increased irrigation treatments resulted in higher average fruit weight and estimated tree yield compared with the standard irrigation, with increases in tree yield of 16-33%. The larger fruit size under increased irrigation treatments was also confirmed by the packout data, which showed an increased percentage in count 12 and reduced percentage in counts 16-20 under most of the increased irrigation regimes. In addition, all increased irrigation treatments reduced the incidence of deformed and sunburned fruit per tree, which was reflected in the increased percentage of fruit packed into premium grade, and reduced percentage in class 1 and bulk grades.

All increased irrigation treatments reduced the dry matter content of the fruit at harvest (all treatments were harvested on the same day). Sensory evaluation indicated no significant treatment effects on general acceptability, aroma and flavour intensity or sweetness. There were some treatment effects on sourness and juiciness, but these were small.

The increased irrigation did not reduce USB, confirming the results of the previous season.

The current research confirms that increased irrigation compared with the standard regime could confer benefits in fruit size, total yield and proportion of premium grade fruit. The lower dry matter content with increased irrigation may also allow later harvest, although increased irrigation effects on the time to on-tree fruit loss (from fruit drop for example) would need to be confirmed to ensure an adequate harvest window. Benefit cost analysis is required to confirm whether the higher costs of irrigation are offset by these potential benefits.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results over the 2011/12 to 2013/14 seasons consistently found that 'Honey Gold' fruit from Dean's farm (Katherine, NT) were less susceptible to USB following abrasion, compared with fruit from nearby Fox Road farm. It was theorised that differing soil water availability could be a potential cause of the difference between the farms. The deep free-draining soil at Fox Road was suggested as a possible cause of greater water stress in the fruit, leading to greater susceptibility to USB. The higher levels of USB in fruit harvested at the hottest time of day also suggested a possible link between water stress and USB susceptibility. A preliminary trial in the 2014/15 season did not confirm an effect of irrigation on USB, but demonstrated significant yield increases and reduced field damage to fruit under increased irrigation. In the 2014/15 season, the recurring difference between the Dean's and Fox Road farms was not repeated in experimental results, with both farms showing similar high levels of USB. This may have been due to extreme environmental conditions at harvest masking the between-farm differences.

The current 2015/16 trial aimed to further investigate whether increased irrigation scheduling at Fox Road could increase the resistance of 'Honey Gold' fruit to USB, and to confirm the previously observed benefits on fruit yield and quality.

Materials and Methods

Treatments

The irrigation trial was conducted at Piñata Farms, Fox Road, a commercial mango farm near Katherine, Northern Territory (NT). Irrigation treatments (Table 1) were applied to whole irrigation blocks (valves) with uniform tree age and soil type (deep loamy sand). Treatments commenced in the week starting 19th July 2015, and continued until 14th November 2015, 3 days prior to trial harvest. The irrigation treatments were applied through the existing irrigation system, with one sprinkler per tree delivering 94 L per hour, using water from on-farm bores. All blocks were sprayed with Screen[®] and Photon[®] at commercial rates and frequencies.

Table 1: Irrigation treatments applied to blocks of 'Honey Gold' mangoes at Fox Road, Katherine, Northern Territory.

Treatment	Stage (from flowering)	Irrigation frequency	Irrigation event duration (h)	Irrigation timing	Total volume (L /tree /week)
Standard*		Every 2 days	2	Night	658
2 per day		2 per day	1	10am and 2pm	1316
3 per day		3 per day	1	10am, 2pm and 2am	1974
High-low	Before 8 weeks	3 per day	1	10am, 2pm and 2am	1974
	After 8 weeks	Every 2 days	2	Night	658
Low-high	Before 8 weeks	Every 2 days	2	Night	658
	After 8 weeks	3 per day	1	10am, 2pm and 2am	1974

*The standard treatment included a slow increase in irrigation from before flowering to full fruit set, followed by the irrigation treatment described. In all other treatments irrigation commenced when panicles were approximately 5-10 cm in length.

Within each irrigation treatment block, 3 sampling rows were selected, with sampling rows separated by one row where possible. Within each row, 10 trees were selected for sampling, with noticeably atypical trees excluded.

Soil water potential

Tensiometers were installed within 2 of the sampling rows in each treatment, with paired tensiometers installed at depths of 30 cm and 60 cm. The tensiometers were located within the wetting zone of the sprinklers and in the drip zone of the tree canopy, at 30 cm from the tree trunk. Soil water potential was recorded every 2-4 days, prior to 8 am. For those treatments receiving irrigation every 2 days, the readings were taken on the morning following a night without irrigation.

Soil moisture

The day before harvest (16th November 2015), soil samples were taken by auger to assess soil moisture content. Samples were taken from soil depths of 0-10, 10-30 and 30-60 cm at 3 randomly selected locations in each of the 3 sampling rows per block, at about 50 cm from the tree trunk. Samples for each row were pooled, and were weighed before and after oven-drying at 65°C to determine moisture content.

Stomatal conductance

Stomatal conductance was measured with a steady state porometer (Decagon Devices, SC-1 Leaf Porometer) on the day after harvest, 18th November 2015, at 6 times across the day. For each of 10 selected trees in each of the treatment blocks, three fully expanded leaves per tree adjacent to fruit were selected at about 1.5 m height, and clearly marked (30 leaves per treatment). Stomatal conductance was measured on the lower surface of each selected leaf in 6 different time periods across the day (6:00-8:30am, 8:40-10:15am, 10:30-11:55am, 1:20-2:45pm, 2:55-4:15pm and 4:25-6:00pm).

Fruit counts, weight and defects

Prior to commercial harvest, on 16-17th November 2015, the number of fruit per tree and fruit defects were recorded. The fruit count was carried out on each of the selected sampling trees (10 trees in each of 3 sampling rows per treatment), with the number of fruit on each tree estimated by averaging 2 independent counts. The number of fruit with sufficient sunburn or deformation due to heat to cause downgrade (for example from premium to first grade) was also recorded.

Following standard commercial harvesting of the 3 selected rows per treatment block, 6 samples of 25 fruit each were randomly selected from across the field bins for each treatment. The total fruit weight per sample of 25 fruit was recorded to determine average fruit weight. The estimated yield per tree was calculated from the fruit count per tree and average fruit weight estimated from the commercially harvested fruit. All fruit from each block were then packed in a commercial pack house, and the block data obtained for the weight of fruit in different size categories and grades (premium, class 1 and 2, and bulk). The percentage in each size or grade was calculated by dividing the weight per grade by the total fruit weight for each block.

Harvest

For the USB abrasion test, fruit were harvested on the 17th November, 2015 from 1:30-3:30pm, prior to the commercial harvest. Twenty fruit were harvested from the 10 selected trees in each of the 3 sampling rows within each irrigation treatment block, totalling 60 fruit per treatment. After harvest, the fruit were de-sapped in Mango Wash[®] and allowed to dry for approximately 2 hours before being abraded.

The % dry matter was assessed from a combined sample of 5 additional fruit per sampling row, resulting in 3 replicate measurements per treatment.

USB abrasion test

The fruit were abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial cold room set at 13°C for 5 days, then placed on a pallet near the rear of a refrigerated 20

pallet road trailer, and transported to Wamuran, South East Queensland (SEQ) at a set temperature of 16°C. A HOBO logger was placed with fruit to record pulp temperature during transport. The fruit were transferred by car to Maroochy Research Facility (MRF), Nambour (SEQ) for assessment.

The fruit treated with 10 ppm ethylene at 20°C for 2 days, then ripened at 20°C until near eating soft. The width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly recorded.

Sensory evaluation

For each treatment, 10 fruit were sampled at eating soft (firmness of 4 on a scale of 1 (hard) to 5 (very soft)). Each tasting sample contained approximately 30 g of diced mango cheek flesh combined from 5 fruit. Treatment groups were randomly assigned 3 digit blinding codes, and were presented in randomly allocated orders of tasting using a Latin square design. Thirty-nine untrained panellists, recruited from MRF staff, assessed each treatment sample for sensory attributes and preference using continuous line scales (Table 2). Samples were served in small lidded plastic containers at room temperature, and panellists were instructed to lift the lid and immediately assess aroma before tasting.

Table 2: Sensory attributes assessed in the ‘Honey Gold’ irrigation trial, with line scale labels.

Sensory attributes or preference	Line scale label at left end (0cm)	Line scale label at right end (10cm)
Overall intensity of aroma	Low aroma intensity	High aroma intensity
Overall intensity of flavour	Low flavour intensity	High flavour intensity
Sweetness	Low intensity sweetness	Extremely sweet
Sourness	Not at all sour	Very sour
Firmness	Not firm	Very firm
Juiciness	Not at all juicy	Very juicy
Overall liking	Dislike	Like very much

Sensory characteristics and preference were quantified using the 10 cm line scales by continuous measured values of 0-10, where 0 values were assigned to the left scale end, and 10 to the right scale end. The Brix of at least 6 fruit in each treatment group was measured, using fruit from the sensory evaluation.

Analysis

Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), with the ‘General Analysis of Variance’ model used to analyse the data, to give an indication of treatment / block differences. The least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment / block means. Treatments were applied to whole blocks, which precluded separating the treatment / block effects. For the ‘standard’ and ‘3 per day’ treatments, very similar treatments had been applied in the previous season. Across the 2 seasons, data were analysed by two-way ANOVA. For sensory data the individual panellist was used as a blocking factor in the analysis.

Results and discussion

Fruit temperature

While the truck was set at 16°C, the fruit pulp temperature measured during transport averaged 18.3°C and ranged from 17.8-20.7°C (Figure 1).

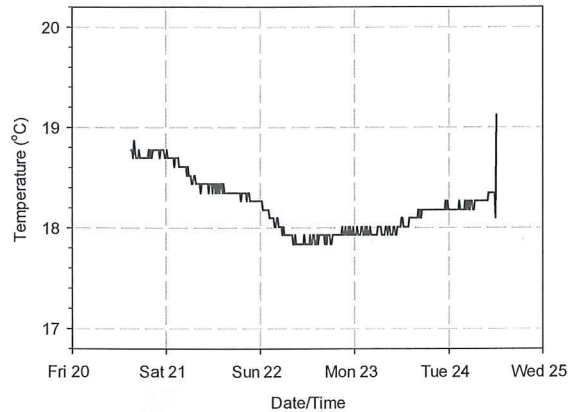


Figure 1: Fruit pulp temperature of 'Honey Gold' mango during refrigerated road freight to Wamuran (south east Queensland), with temperature set at 16°C.

Soil and tree water status

At 30 cm soil depth the 2 per day and high-low irrigation treatments resulted in significantly less negative water potential than the standard treatment (Table 3). Under both the 2 per day and high-low treatments, the average water potential at 30 cm depth across the season was less negative than typical field capacity (-8 to -10 kPa), suggesting that these treatments may have actually resulted in higher than optimal soil water potential. In contrast, at 60 cm depth, the 2 per day and high-low treatments showed significantly more negative water potential across the season. For the 2 per day treatment, despite applying twice the total volume of water per week, the soil appeared to be drier at depth. This is likely due to greater evaporative loss with this treatment because of the shorter 1 hour applications during the hotter times of the day, and less water availability to penetrate the lower profile.

Soil water potential during 23rd October to 4th November 2015 showed no significant treatment effect at either 30 or 60 cm depth. The standard and high-low treatments are the same from 8 weeks after flowering, and the lack of difference between the standard and 2 per day irrigation may be due to irrigation timing and duration, as outlined above.

Table 3: Soil water potential at 30 and 60 cm depth in the drip zone of 'Honey Gold' mango trees receiving standard irrigation (every second day), 2 per day (irrigation twice per day) or high-low (3 irrigation events per day until 8 weeks after flowering, followed by standard irrigation). Means within each column with the same letter are not statistically different (P=0.05).

Treatment	Soil water potential (kPa)			
	22 nd July to 4 th Nov		23 rd Oct to 4 th Nov	
	30 cm	60 cm	30 cm	60 cm
Standard	-7.4 ^a	-8.5 ^b	-7.7	-10.2
2 per day	-6.3 ^b	-10.4 ^a	-6.6	-10.7
High-low	-6.3 ^b	-9.6 ^a	-6.7	-10.8

The standard irrigation treatment appeared to result in more fluctuation in soil moisture potential at 30 cm depth than the 2 per day and high-low treatments (Figure 2). At 60 cm, all treatments showed a degree of fluctuation in soil water potential, with the high-low regime tending to show the least variability.

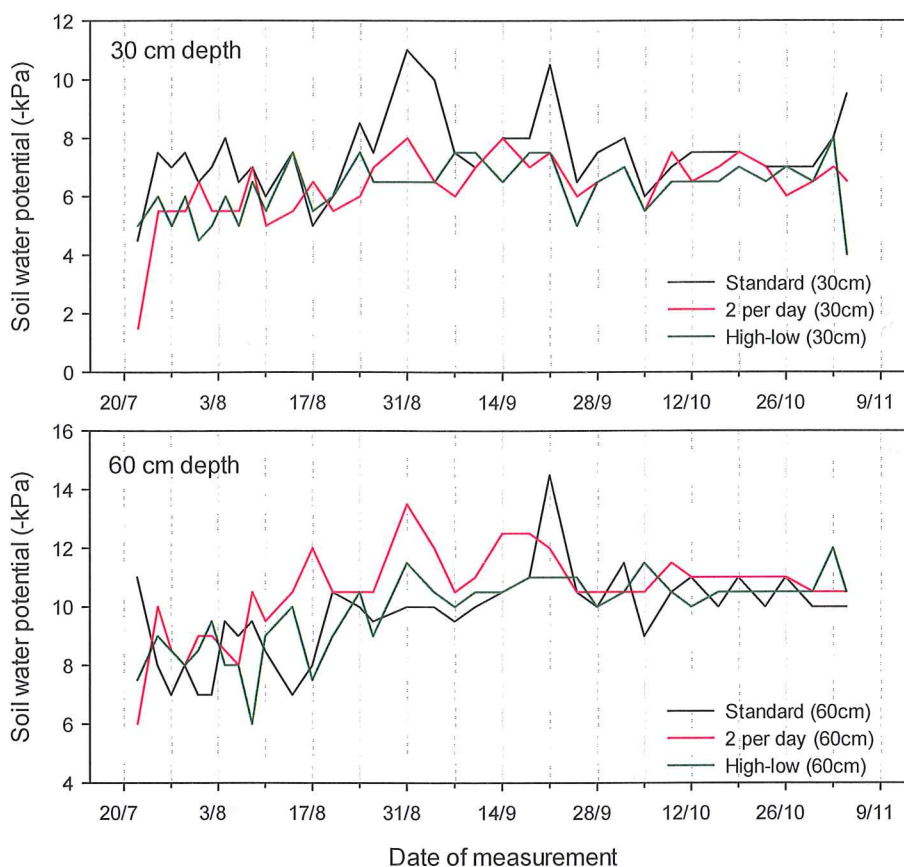


Figure 2: Soil water potential (-kPa) under various irrigation treatments of standard irrigation (every second day), 2 per day (irrigation twice per day) or high-low (3 irrigation events per day until 8 weeks after flowering, followed by subsequent standard irrigation).

Soil moisture content at 0-60 cm just prior to harvest was highest under the 3 per day and low-high treatments (Table 4). Both these treatments were being irrigated with 3 times the volume of water compared with standard irrigation. In contrast, the 2 per day and high-low treatments did not significantly differ from the standard irrigation regime. These effects are likely because the high-low treatment was the same as the standard treatment from 8 weeks after flowering, and the 2 per day treatment was applied in 1 hour irrigation events during the hotter times of the day.

Table 4: Soil moisture content at several soil depths in the 'Honey Gold' mango irrigation treatments just prior to harvest. Means within each column with the same letter are not statistically different (P=0.05).

Irrigation treatment	Soil moisture content (%)		
	0-10 cm	10-30 cm	30-60 cm
Standard	5.0 ^c	5.8 ^b	6.2 ^b
2 per day	5.7 ^{bc}	6.2 ^{ab}	6.5 ^b
3 per day	8.2 ^a	6.7 ^a	7.4 ^a
High low	5.5 ^{bc}	5.7 ^b	6.6 ^b
Low high	6.8 ^b	6.6 ^a	7.2 ^a

Leaf stomatal conductance increased from early morning to midday in all treatments, as expected (Figure 3). The higher conductance in the 2 per day and low-high treatments implies less tree water stress, consistent with the greater volume of irrigation applied in these treatments.

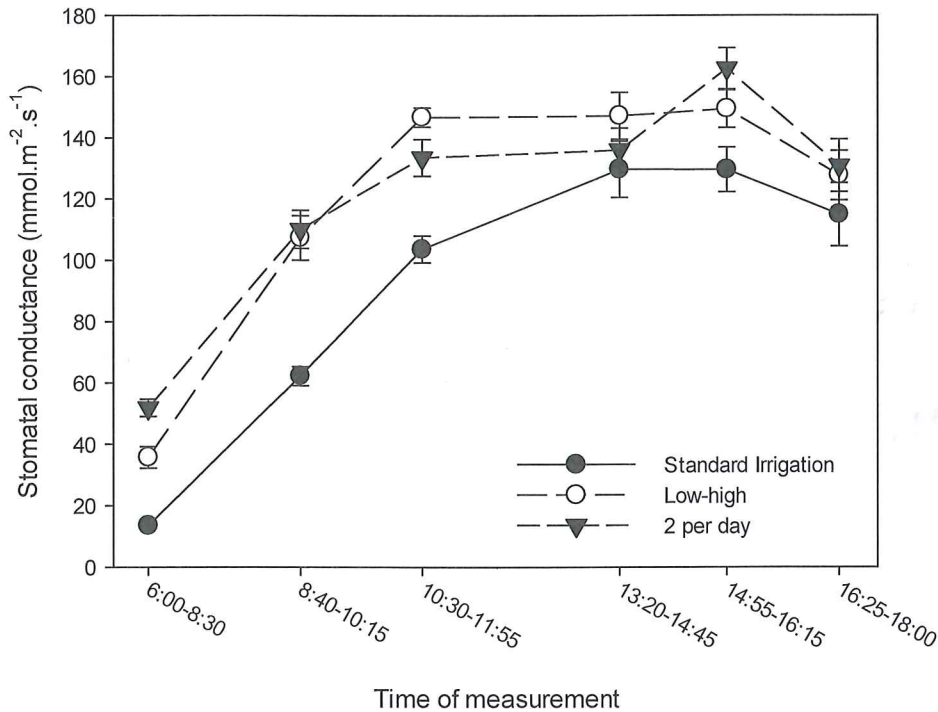


Figure 3: Stomatal conductance of 'Honey Gold' mango tree leaves at several times during the day following harvest. The trees received irrigation every second day (standard) or irrigation twice per day (2 per day), or standard irrigation until 8 weeks after flowering, followed by 3 irrigations per day until harvest (low-high). Error bars show standard error of the mean.

Under skin browning

Irrigation treatment had no effect on USB (Table 5), which was consistent with results from last season. The combined analysis of both seasons similarly showed no significant effect of irrigation on USB susceptibility (data not shown). These results suggest that water availability may not be the cause of the greater susceptibility to USB of fruit harvested in the early afternoon.

Table 5: Effect of various irrigation regimes on USB incidence (% of fruit with USB greater than 1cm²) and severity (area of the USB on fruit with USB) in 'Honey Gold' mangoes.

Irrigation treatment	Incidence of any USB > 1cm ² (%)	Total USB area per fruit where USB occurred (cm ²)
Standard	93.7	42.0
2 per day	86.2	56.2
3 per day	88.7	56.4
High low	93.3	57.1
Low high	85.3	48.7
Average LSD	10.9	14.5
Sample size	60-65	54-59

Fruit packout and quality

In the 2014/15 season increased irrigation significantly increased the number of fruit per tree. A similar trend was observed in the present trial, although the results were not statistically significant (Table 6). The low-high treatment showed the highest average fruit weight. The 2 per day and high-low treatments also showed significantly increased fruit weight compared to standard irrigation. The dry matter content was significantly lower under all the increased irrigation treatments compared to the standard irrigation. The increased fruit weight with increased irrigation was probably largely due to greater uptake of water into the fruit, which also resulted in the lower dry matter content. All increased irrigation treatments resulted in significantly increased estimated tree yield, with the low-high irrigation treatment estimated to produce 32% greater yield than the standard irrigation treatment.

All the increased irrigation treatments also significantly reduced the incidence of deformed and sunburned fruit.

Table 6: Effect of irrigation treatment on 'Honey Gold' fruit number per tree, average fruit weight, percent dry matter, and percentage of fruit deformed or with sunburn. Estimated tree yields were calculated from fruit count and weight. Means within each column with the same letter are not statistically different (P=0.05).

Irrigation treatment	Fruit count per tree	Average fruit weight (g)	DM (%)	Deformed fruit (%)	Sunburned fruit (%)	Estimated total tree yield (kg)
Standard	70.1	478.6 ^c	18.95 ^a	2.73 ^a	0.32 ^a	33.5 ^c
2 per day	74.6	521.5 ^b	17.25 ^b	1.52 ^b	0.09 ^b	38.9 ^b
3 per day	79.2	500.4 ^{bc}	16.84 ^b	0.36 ^c	0.00 ^b	39.6 ^b
High low	78.5	524.9 ^b	16.74 ^b	1.40 ^b	0.08 ^b	41.2 ^{ab}
Low high	78.9	559.7 ^a	16.67 ^b	1.31 ^b	0.08 ^b	44.2 ^a
LSD	8.42	31.07	1.17	0.76	0.20	4.39
Sample size	30	6	3-7	30	30	30

Based on the packhouse data, the 2 per day treatment resulted in the highest proportion of premium grade fruit, primarily because of a lower percentage in Class 1 (Table 7). However, all the increased irrigation treatments resulted in a greater percentage of fruit in premium grade, and a reduction in the percentage of bulk grade fruit.

Table 7: Effect of irrigation treatments on the percentage (by weight) of fruit in each grade for 'Honey Gold' mangoes, as obtained from commercial packout data.

Irrigation treatment	Premium	Class 1	Class 2	Bulk
% in each grade (by weight)				
Standard	55	32	3	11
2 per day	71	18	2	9
3 per day	63	27	3	7
High low	65	27	3	5
Low high	63	26	3	8

The 2 per day, 3 per day and high-low treatments resulted in a higher proportion of fruit in size 12 count, and fewer in the smaller sizes of count 16-20 when compared to standard irrigation (Figure 4). This confirms the data for fruit number and average fruit weight per tree presented in Table 6. However, the low-high treatment showed a similar fruit size distribution to standard irrigation, which is contrary to the Table 6 results.

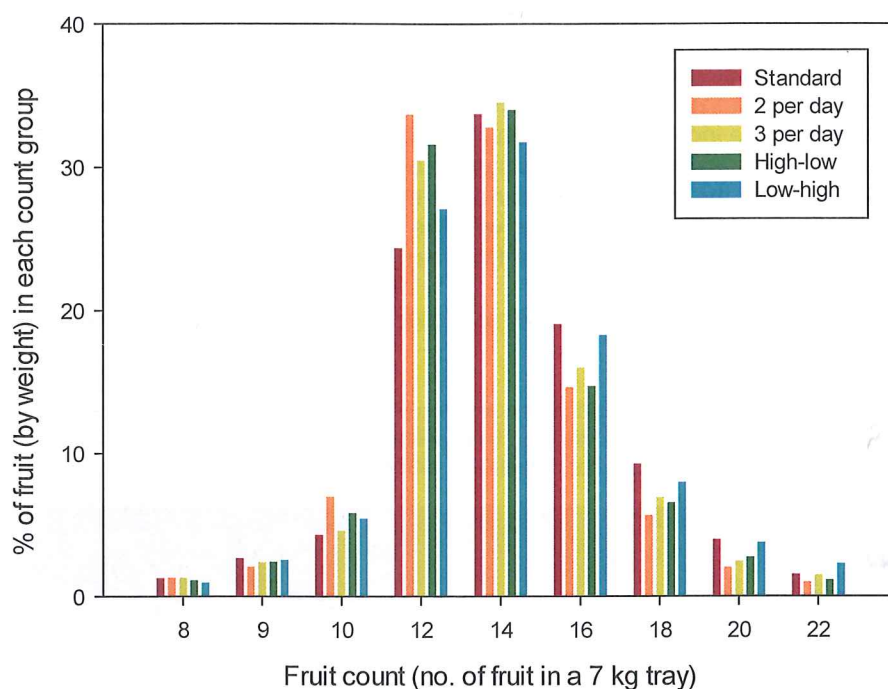


Figure 4: The effect of irrigation treatments on the percentage of 'Honey Gold' fruit (by weight) in each size count (number of fruit in a 7 kg tray), obtained from commercial packout data.

Sensory evaluation

All treatments produced fruit with acceptable flavour (Table 8). Fruit from the standard and low high treatments were rated as more sour and more juicy than most of the other treatments, but the differences were small. There were no statistically significant treatment effects for the other parameters, however there was a consistent trend for the standard treatment fruit to have higher Brix, aroma and flavour intensity, and sweetness and acceptability. This would be expected from the higher dry matter content in the standard treatment fruit at harvest.

Table 8: Sensory evaluation and °Brix of 'Honey Gold' mango fruit grown under various irrigation regimes. Means with the same letter within each column are not significantly different at $P < 0.05$ as tested by LSD. Sensory characteristics were assessed by 39 panelists using line scales rated as 0-10, where 0=low (aroma, flavour, sweetness) or not at all (sour, juicy) and 10=high (aroma, flavour), extremely (sweet) or very (sour, juicy). Acceptability was assessed using a preference line scale rated from 0-10, where 0=dislike and 10=like very much.

Treatment	°Brix	Aroma intensity	Flavour intensity	Sweetness	Sourness	Juiciness	Acceptability
Standard	19.1	6.1	6.8	6.0	4.6 ^a	5.8 ^a	6.7
2 per day	17.4	5.4	6.0	5.5	4.0 ^{abc}	4.7 ^b	5.9
3 per day	17.6	4.9	6.1	5.5	3.3 ^c	5.2 ^b	5.9
High low	18.3	5.1	6.2	5.0	3.8 ^{bc}	5.2 ^b	6.3
Low high	17.4	5.5	6.3	5.4	4.2 ^{ab}	5.8 ^a	6.3
LSD	1.5-1.9	0.91	0.73	0.71	0.76	0.59	0.69
Sample size	6-9	39	39	39	39	39	39

Flavour intensity and sweetness were the most highly weighted (most important) attributes determining acceptability, with the acceptability score showing a moderate positive correlation with both (correlation coefficient 0.55 and 0.49, respectively). These attributes were also correlated with each other, with sweetness and flavour intensity showing a moderate-strong positive correlation coefficient of 0.60. Aroma intensity and juiciness also had an influence on acceptability, with weak positive correlation coefficients of 0.31 and 0.38, respectively. These results suggest that the attributes most favoured by the panellists were flavour intensity, sweetness, juiciness and aroma intensity.



Conclusions

Increased irrigation did not reduce USB susceptibility, confirming the results observed last season. However, increased irrigation increased fruit weight and estimated tree yield by 16-33%, and reduced the percentage of fruit with commercially significant sunburn and misshapen form. These results were generally confirmed by commercial packout data from the packhouse.

There was little consistent difference within the higher irrigation treatments, although further commercial testing over several seasons may be required to verify this. Benefit cost analysis would determine if the benefits of increased yield and premium packouts are greater than the extra irrigation costs, and whether the shift to a slightly bigger fruit size has a bearing on returns.

Calcium and phosphorus effects on USB

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Bhavisha Mehta, Gavin Scurr

(2014/15)

This publication has been compiled by Peter Hofman of AgriSciences Qld, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango is susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. It occurs primarily in fruit grown in the hotter production areas, especially the Northern Territory. Previous research indicated that fruit harvested in the afternoon were significantly more susceptible to USB than those harvested at night or in the morning. Also, two farms in the Katherine area of the Northern Territory produced fruit with differing susceptibility to USB over several years. Dean's farm soil type is sandy loam to clay while that of Fox road is deep loamy sand. Also irrigation water used at Dean's is from the Katherine River with good quality and near neutral pH, while water with high calcium content and approximately pH 8.5 is used at Fox Road. Hence it is possible that soil type and pH play a role in the differing USB susceptibility of fruit from these farms.

A very preliminary trial was established at Fox road to test the impact of these differences. Additional phosphorus (super phosphate which contains additional calcium) was applied just before flowering to one row of 'Honey Gold' trees. On an adjacent block, double the commercial rate of bio gyp (a liquid formulation of gypsum for fertigation) was applied during the early stages of flowering and fruit growth. These preliminary results suggested that the treatments decreased the susceptibility of fruit to USB based on the USB abrasion test. These results justify further research in the following season.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, small seed size and good shelf life. However, the variety has shown susceptibility to underskin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results over the last three seasons have consistently found that Honey Gold mango fruit from Dean's farm in Katherine are less susceptible to USB following abrasion, compared with fruit from Fox Road farm. These farms are about 15 km distant. One of the possible causal mechanisms is nutritional, and especially in relation to calcium (Ca) because of its well-recognised role in physiological disorders of fruit.

One of the key differences between the Dean's and Fox Road (often producing more susceptible fruit) farms is soil pH; the soil pH at Deans is typically 5-6 and at Fox Rd about 8 based on previous soil tests (Appendix 1). There is some evidence that this difference in pH is affecting leaf nutrients but the effects are not marked. However, it is worth testing the effects of lower soil pH on the Fox Rd trees.

Materials and Methods

Treatments

This exploratory trial was conducted at Fox Rd, Katherine. The treatments were applied to whole blocks or rows, as follows:

1. Control; management block 6, on row 9
2. Sulphur treatment to reduce pH; block 6, row 10
3. P treatment 200 g triple super /tree; block 6, row 8
4. P treatment 400 g triple super /tree; block 6, row 7
5. Double Bio gyp liquid in the irrigation system; the whole of block 21 whole valve

The sulphur was applied with the first irrigation, on about 21st July, 2014. Sulphur was applied at a rate estimated to reduce pH to 5-6 (similar to the soil pH on Dean's farm). The equivalent of 3 t ha⁻¹ of elemental sulphur or 3 kg tree⁻¹ of elemental S was applied. It was spread as a 3 m strip along both sides

of the trees then watered in well. The P treatments were applied just before flowering as a broadcast treatment under the drip zone of each tree.

Soil analysis at the end of October 2014 indicated that there was no effect of the sulphur treatment on soil pH, most likely because of dependency on bacterial activity to convert sulphur to sulphuric acid. More sulphur was applied in late October 2014 and January 2015 for later assessment. Because of nil effect of the sulphur treatment on pH, only treatments 1, 3, 4 and 5 were assessed.

USB abrasion test

One tray was harvested from each of six trees for each of the four treatments (total of 24 trays). The fruit were de-sapped in Mango Wash[®] and allowed to dry for about 2 hr. The fruit were then abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander at a speed setting of five (on a scale of 1-6), using 60 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial 12°C-set cold room for at least six days, then placed on a pallet near the rear of a 20 pallet standard refrigerated road trailer, and transported to Wamuran at a set temperature of about 14°C.

The fruit were ripened at about 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion, and of the USB lesion (including the abraded area) were measured separately, and the area of each calculated using the formula for an ellipse. The USB area was then calculated by subtracting the abrasion area from the USB + abrasion area. Where required the areas were converted to a rating score of:

- 0 = nil,
- 1 = up to 1 cm²,
- 2 = 1 to 3cm²,
- 3 = 3 to 12cm² (10%),
- 4 = >12cm² (10%) and <25%,
- 5 = >25% of the fruit surface area affected.

USB was also observed on areas of the fruit that were not abraded with sandpaper. These were assumed to have been caused by normal commercial practices from packing onwards. These USB areas were also calculated as above.

Fruit skin samples

Skin samples were taken from three of the ripe USB fruit per tree after final assessment, with one sample taken per treatment. The samples were dried at about 65°C to constant weight then held at about -18°C before analysis by SGS (Brisbane) using standard techniques.

Statistical analysis

This trial was designed as an exploratory trial, with the intention of repeating in following seasons assuming promising results. Due to the small scale of the trial and limitations of field application, the experimental design did not include true replication. Statistical analyses were performed by Genstat[®] 14 for Windows[™] (VSN International Ltd., UK), with the 'General Analysis of Variance' model used to analyse the data, to give a preliminary indication of treatment differences. In all trials, the least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means.

Results and discussion

USB

The preliminary results suggested that the P and Biogyp treatments reduced the area of USB around abrasion sites (based on the average across all abrasion sites), but had little effect on the average severity on those sites with USB (Figure 1).

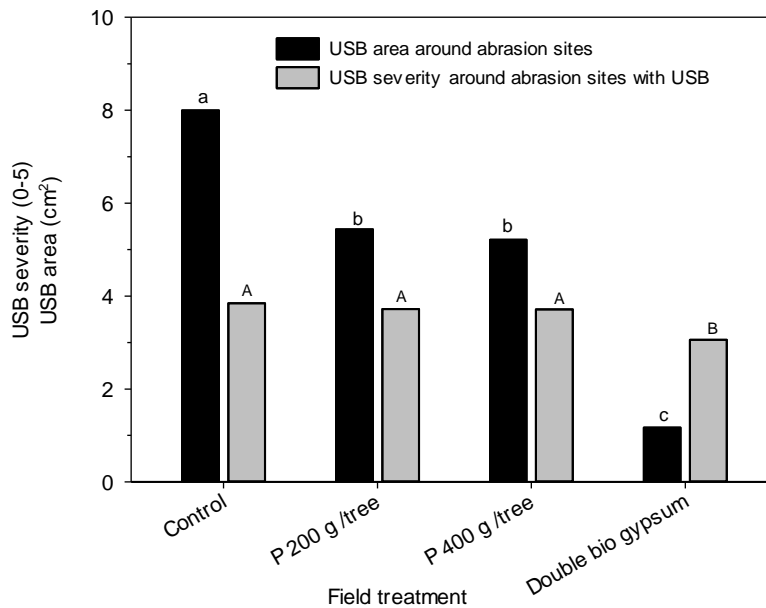


Figure 1. Phosphorus at two rates, and Biogyp (calcium) effects on under skin browning on ripe 'Honey Gold' mango following abrasion at four locations on the fruit, then holding at about 12°C before ripening and assessment. Six trays (about 84 fruit) per treatment were assessed. The average USB severity was based on only those abrasion areas that developed USB. Bars with the same letters within each measure are not significantly different (P=0.05).

However, the treatments significantly reduced the percentage of abrasion sites with USB (Figure 2). This suggests that the main effects were on the susceptibility of the fruit to develop USB, rather than on the area of USB around each abrasion point. Superphosphate contains about 18% Ca, so it is possible that the super effect was via the additional Ca applied.

The results of this preliminary trial indicate that further research is warranted in exploring the benefits of phosphorus and Biogyp treatments in reducing USB susceptibility.

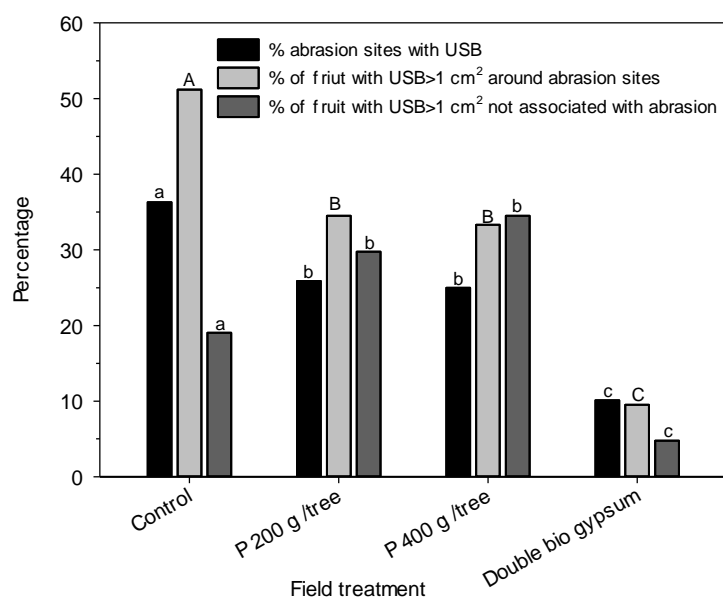


Figure 2. Phosphorus at two rates, and double rate Biogyp (calcium) effects on under skin browning on ripe 'Honey Gold' mango following abrasion at four locations on the fruit, then holding at about 12°C before ripening and assessment. Six trays (about 84 fruit) per treatment were assessed. Bars with the same letters within each measure are not significantly different ($P=0.05$).

Fruit skin minerals

There was no replication for skin analysis. However the results suggest that skin Ca was lower in the Biogyp treatment, resulting in double the N/Ca ratio of that in flesh from the other treatments. This was surprising given the treatment was designed to increase fruit Ca concentrations.

Table 1. Phosphorus at two rates, and double rate Biogyp (calcium) effects on fruit skin minerals in 'Honey Gold' mangoes.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	N/Ca
Control	0.5	0.08	0.85	0.66	0.15	0.76
200 g triple super/tree	0.5	0.08	0.96	0.50	0.14	1.00
400 g triple super/tree	0.5	0.08	0.87	0.57	0.16	0.88
Double bio gypsum liquid	0.7	0.07	0.7	0.32	0.19	2.19

Appendix 1

Soil pH at two Katherine (Northern Territory) farms. Dean's Farm has consistently produced 'Honey Gold' mango fruit more tolerant to USB, compared with fruit from Fox Road.

Farm	Sample month/year							
	5/07	12/07	11/08	11/09	11/10	10/11	11/12	11/13
Deans								
'Honey Gold' 1 sandy	6.3	6.7	5.7	6.8	6.4	6.7	7.2	6.9
'Honey Gold' 2 grey	5.2	5.6	4.8	6.3	4.9	5.5	6.1	5.5
Fox Road								
Valves 6-7-8	8.3	9	8.2	8.9	8.6	8.2	9.0	8.5



Nutrition effects on USB susceptibility in 'Honey Gold' mango.

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Pip Bryant, Hung Duong,
Gavin Scurr

(2015/16)



This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest and subsequent low temperature storage and vibration damage in transport.

In the 2014/15 season a preliminary trial was carried out at Fox Road farm, in the Katherine region of the Northern Territory testing the effects of phosphorus and calcium treatments on USB susceptibility. The trial showed some promising results, with applications of super phosphate and double the commercial rate of Biogyp (a liquid formulation of gypsum for fertigation) appearing to reduce USB. Based on these preliminary results, a further trial using randomised block design was undertaken to more rigorously test the effects of nutritional treatments on USB.

Nutrition treatments of triple super and gypsum were applied at 2 levels of application rate near the commencement of flowering. A double biogyp treatment was applied by fortnightly fertigation at double the recommended rate for 6 weeks following flowering. The fruit were harvested and abraded using a technique developed to induce USB, cool stored for 10 days, and then transported to Maroochy Research Facility for ripening and USB assessment.

The promising results of reduced USB incidence and severity observed in the previous season were not confirmed in this study. However strong block differences were found in the USB response, with block 1 showing noticeably lower incidence of USB than the other blocks.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

A preliminary trial was undertaken in the 2014/15 season comparing USB susceptibility under various nutrition treatments, including 2 levels of super phosphate application and double the commercial rate of bio gyp (a form of gypsum applied by fertigation). These treatments all appeared to reduce the susceptibility of 'Honey Gold' mangoes to USB, with bio gyp showing particularly promising results. The preliminary trial was carried out with the control and super phosphate treatments applied to separate single rows within a block, while the bio gyp was applied by fertigation to a nearby separate block. This experimental design did not allow block or row effects to be determined, so these may have contributed to the effects observed. The current trial used a randomised block design to more rigorously test the effects of these nutritional treatments on USB susceptibility.

Materials and Methods

Treatments

Nutrition treatments, as described in Table 1, were applied to trees in a commercial orchard at Fox Road, Katherine, NT, on 25th June, 2015. At this stage, some of the panicles had flowered but most buds were just pushing. The fertilisers were spread within the dripline of the tree, typically about 3 m in diameter. The trees received 2 h of irrigation (about 660 L) on the same day.

Table 1: Nutrition treatments applied to 'Honey Gold' mangoes grown at Fox Road, Katherine, NT.

Treatment	Details
Control	Standard nutrition, including Biogyp (32% Ca) at 320 mL/tree by fertigation at each irrigation (2-3 times per week) for 3 weeks before full flowering, and another 6 weeks after full flowering. 156g of P was applied as 55S after harvest.
P-500	An extra 500g of triple super (18% P) was applied to each tree as a broadcast application, in addition to the standard nutrition regime.
P-1000	An extra 1000g of triple super (18% P) was applied to each tree as a broadcast application, in addition to the standard nutrition regime.
Gypsum-500	An extra 500g of gypsum was applied to each tree, in addition to the standard nutrition regime.
Gypsum-1000	An extra 1000g of gypsum was applied to each tree, in addition to the standard nutrition regime.
Double Biogyp	Double the commercial rate of Biogyp was applied by fertigation every 2 weeks after full flowering until about 6 weeks after flowering (3-4 applications) , in addition to the standard nutrition regime.

Sulphur

Sulphur was applied in a separate trial, but utilising some of the same control trees as the nutrition trial. Trees that had previously been treated with sulphur to attempt to reduce soil pH were treated with additional sulphur, and compared against control trees. Elemental S was applied in 2014/15 (as 3 applications of 3 kg in June 2014, December 2014 and March 2015). The soil pH on 3rd June was 7.7 in the treated soil, and 8.3 for the control, and soil sulphur content was 45 and 15 ppm respectively. Additional S was applied to the same trees (Valve 6, row 10, trees 2-11) on 24th June 2015 in a single application of 6 kg per tree, spread within the dripline of the tree. The trees received about 660 L water after application.

Experimental design

The trial was conducted in valve 6 and 7 irrigation blocks, with each block split into two to provide 4 statistical blocks (Figure 1). The trees used in the trial were around 12 years old, with 1.5 m canopy radius, and 8 m row spacing, with sprinkler irrigation confined to the dripline of the trees. The treatments were randomly applied to individual rows within each of the 4 blocks in a randomised block design, with an untreated buffer row between each neighbouring block. The double biogyp fertigation was applied to whole rows by turning off the taps to all other rows at the time of application, resulting in slightly more water being applied to this treatment group (about 20 min for each fertigation). The other treatments were applied to 10 trees within each row. The treatments were offset between rows, alternating between trees 2-11 and 12-21, to avoid different treatments being applied to neighbouring trees.

One of the rows included in the trial had previously been treated with sulphur to attempt to reduce the soil pH. The sulphur treated trees were treated with additional sulphur, and were compared against the corresponding control within the block (block 4).

Figure 1: Application of treatments to rows of 'Honey Gold' mangoes in 4 statistical blocks within 2 irrigation blocks (valve 6 and 7) at a commercial orchard in Fox Road, Katherine, NT.

Tree no	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Row	Valve 7																																
1																																	
2	Gypsum 1000: trees 2-11																																
3	Double biogyp: trees 12-21																																
4	P-1000: trees 2-11																																
5	Gypsum 500: trees 12-21																																
6	Control: trees 2-11																																
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3	Double biogyp: trees 2-11																																
4	Control: trees 12-21																																
5	Gypsum 500: trees 2-11																																
6	Gypsum 1000: trees 12-21																																
7																																	
8	Double biogyp: trees 2-11																																
9	Control: trees 12-21																																
10	<i>Sulphur treatment; trees 2-11</i>																																
11	Gypsum 500: trees 2-11																																
12	P-500: trees 12-22																																
13	Gypsum 1000: trees 2-11																																
14	P-1000: trees 12-21																																

Leaf and fruit skin samples for nutrient analysis

Leaf and skin samples were taken for nutrient analysis. Skin samples were taken from 5 fruit in each treatment row at eating ripe, and were oven dried at 60°C to a constant weight. The samples were then frozen for later analysis. With a lack of treatment effect on USB, but strong block effects, only the control samples from the 4 statistical blocks were analysed for nutrients.

Harvest

The fruit were harvested on 23rd October, at 1:30-3:15pm, and were considered immature for harvest (slabby and dark green in colour). In block 1 and 2, the most mature fruit available were selectively picked, while in block 3 and 4 fruit of typical maturity were picked. At harvest, 8 typical trees were selected from each of the 10 treatment trees per row. A total of 14 fruit were harvested from each treatment row (about 1-2 fruit from each of 8 trees). The day before the trial harvest, 12 fruit from each row (1-2 from each tree) were harvested to measure dry matter.

USB abrasion test

The harvested fruit were desapped in Mango Wash[®] and allowed to dry for about 2 hr. The fruit were abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a

commercial cold room set at 15°C for 10 days, and then placed on a pallet near the rear of a refrigerated road trailer, and transported to Wamuran, South East Queensland (SEQ) at a set temperature of 14°C. The fruit were transported by car to Maroochy research Facility (MRF), Nambour (SEQ) for assessment.

The fruit were ripened at 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each was calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly recorded

Analysis

Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), using the 'General Analysis of Variance' model, with replicate blocks as a blocking factor and individual fruit as experimental units. The least significant difference (LSD) procedure at P=0.05 was used to test for differences between treatment means.

Results and discussion

Fruit temperatures

Fruit temperatures were maintained at approximately 15°C for about 10 d before transport and at 16-22°C during transport (Figure 2). Relative humidity (RH) increased during storage as a result of fruit respiration.

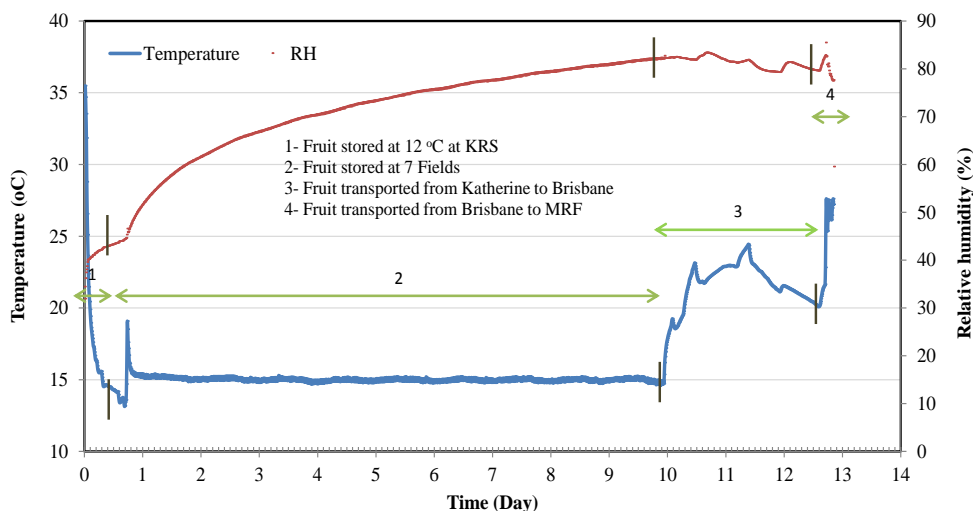


Figure 2: Fruit temperatures following the USB test, and during road freight to Wamuran (south east Queensland)

USB incidence and severity

The nutrition and sulphur treatments trialled did not result in any significant differences in USB incidence or severity (Table 2, Table 3). However, strong block differences were observed in the USB response, with statistical block 1 showing much lower incidence of USB than the other blocks (Table 4). The fruit from this block also tended to show a lower severity of the disorder, with the area of USB on affected fruit roughly half that of the other blocks. It was noted in the field that the valve 6 trees (statistical block 3 and 4) appeared more "hungry" than valve 7 (block 1 and 2), with less leaf cover and more yellow leaves and fruit. The block 1 trees were noted to be greener, and to have fruit that appeared less mature. In a previous trial fruit harvested 3 weeks before commercial maturity showed lower susceptibility to USB than more mature fruit. While block 1 fruit tended to have a lower dry matter, indicative of more immature fruit, no significant variation in %DM between blocks was detected.

Table 2: Effect of super, gypsum and biogyp nutrition treatments on USB incidence and severity of USB in ‘Honey Gold’ mangoes grown at Fox Road, Katherine, NT

Treatment	Incidence of any USB > 1cm ² (%)	USB severity - USB area per fruit in affected fruit (cm ²)
Control	18.6	14.3
500g triple super	28.6	12.1
1000g triple super	39.3	17.8
500g gypsum	34.6	23.1
1000g gypsum	28.6	12.5
Double biogyp	28.6	16.9
Average LSD	12.85	12.07
Sample size	64	8-23

Data analysed by ANOVA with blocking, with fruit as the experimental unit.

Table 3: Effect of sulphur application on USB incidence and severity of USB in a nutrition trial on ‘Honey Gold’ mangoes grown at Fox Road, Katherine, NT

Treatment	Incidence of any USB > 1cm ² (%)	USB severity - USB area per fruit in affected fruit (cm ²)
Control (block 4)	18.8	25.0
Sulphur	40.0	19.8
Average LSD	26.37	21.91
Sample size	16-70	3-29

Data analysed by ANOVA, with fruit as the experimental unit.

Table 4: Block differences in % dry matter, USB incidence and severity of USB in a nutrition trial on ‘Honey Gold’ mangoes grown at Fox Road, Katherine, NT.

Statistical block	%DM	Incidence of any USB > 1cm ² (%)	USB severity - USB area per fruit in affected fruit (cm ²)
Block 1	17.40	13.4 ^b	8.96
Block 2	17.80	32.7 ^a	15.97
Block 3	17.87	41.0 ^a	17.93
Block 4	17.82	34.5 ^a	18.95
Average LSD	0.467	13.69	9.07
Sample size	2	82-87	13-35

Data analysed by ANOVA with blocking, with fruit as the experimental unit. Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Nutrition analysis

The skin and leaf samples from the 4 control blocks were compared by nutrient analysis to determine if any obvious differences existed between the blocks that may have resulted in lower susceptibility in block 1. Leaf analysis did not reveal any substantial differences in block 1 compared to the other blocks (Table 5). The greatest difference observed was leaf calcium being around 20% lower than the average of the other 3 blocks. Some noticeable differences were observed in fruit skin analysis (Table 6). Skin samples from Block 1 revealed higher calcium, zinc, iron, manganese and molybdenum, all of which were >30% higher than the other 2 blocks analysed. Previous soil, skin and leaf nutrient analysis in USB trials have not tended to show any consistent trends in nutrient levels linked to USB susceptibility.

Table 5: Nutrient analysis of ‘Honey Gold’ mango leaf tissue, comparing the 4 statistical blocks used in the trial at Fox Road, Katherine, NT.

Leaf	N %	P %	K %	Ca %	Mg %	Na %	S %	Zn mg/kg	Fe mg/kg	Cu mg/kg	Mn mg/kg	B mg/kg	Mo mg/kg
Block 1	0.7	0.09	0.60	2.35	0.32	0.01	0.12	38	130	330	110	85	5
Block 2	0.7	0.09	0.53	2.86	0.31	0.01	0.12	46	130	370	100	110	5
Block 3	0.5	0.08	0.52	3.09	0.30	0.01	0.11	39	110	290	110	84	4.6
Block 4	0.7	0.08	0.53	2.90	0.24	0.01	0.10	45	100	320	110	78	5
%D*	11	8	14	-20	13	0	9	-12	15	1	3	-6	3

* %D shows the % difference between block 1 and the average of the other blocks.

Table 6: Nutrient analysis of ‘Honey Gold’ mango skin tissue, comparing the 4 statistical blocks used in the trial at Fox Road, Katherine, NT.

Skin	P %	K %	Ca %	Mg %	Na %	S %	Zn mg/kg	Fe mg/kg	Cu mg/kg	Mn mg/kg	B mg/kg	Mo mg/kg
Block 1	0.06	0.74	0.72	0.18	<0.01	0.05	5.2	57	21	8.1	22	0.25
Block 2	*	*	*	*	*	*	*	*	*	*	*	*
Block 3	0.07	0.93	0.54	0.14	<0.01	0.04	3.8	19	21	6.4	19	0.11
Block 4	0.07	0.87	0.56	0.15	<0.01	0.04	3.8	25	26	5.8	20	0.18
%D*	-14	-18	31	24	0	25	37	159	-11	33	13	72

* %D shows the % difference between block 1 and the average of the other blocks.

Conclusions

The beneficial effects of nutrition treatments on USB incidence and severity observed the previous season were not repeated in this trial. Significant block differences were found in the USB response, with one block showing noticeably lower incidence of USB than other blocks. This may have been related to fruit maturity or other inherent differences between the blocks. The strong block effect observed in this trial reinforces the need for sound experimental design in assessing potential treatments in USB research.

Effects of postharvest application of methyl jasmonate, salicylic acid and oxalic acid on USB of 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Pip Bryant, Peter Hofman, Ted Winston, Gavin Scurr

(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a superficial discolouration under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest, subsequent low temperature storage and vibration damage in transport.

Low storage temperatures after harvest have been shown to increase USB, suggesting that treatments used to prevent chilling injury (CI) may be worth exploring as potential treatments for USB. Methyl jasmonate (MeJA), salicylic acid (SA) and oxalic acid (OA) are natural plant compounds that have shown promise in reducing CI in mango. These were applied as postharvest vapour or dip treatments to 'Honey Gold' fruit harvested from Fox Road, Katherine, Northern Territory (NT). Following treatment the fruit were abraded and then stored and transported at low temperature, and the resultant USB on the ripe fruit assessed.

Fruit treated with MeJA vapour at 0.01mM and OA dip at 5mM showed significantly reduced USB incidence compared to control treatments. USB greater than one cm² was observed in over 80% of fruit in the control treatments, while 0.01mM MeJA and 5mM OA treatments both resulted in 61.9% incidence. The severity of resultant USB was also reduced by the MeJA and OA treatments, with USB area typically halved compared to the control treatment.

The postharvest application of natural plant compounds to reduce USB has shown promising results, with significant reductions in USB observed. Further research is required to confirm these results, and to determine optimal rates of application.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

USB in 'Honey Gold' mango has been linked with physical damage to the fruit in association with storage at low temperatures. The fact that low storage temperatures exacerbate USB suggests that treatments used in the prevention of chilling injury (CI) may be worth exploring as potential treatments for USB. It has been hypothesised that stress treatments applied at a mild, non-damaging level are able to induce tolerance to other forms of biotic or abiotic stress (Meir et al., 1996). Many treatments used to reduce CI appear to act in this way, causing a mild stress that increases tolerance to further stress.

Jasmonates are natural plant growth regulators involved in defence responses to biotic and abiotic stresses, including cold stress. The application of jasmonates initiates similar responses to those induced by abiotic stress, including the production of heat-shock proteins (Ding et al., 2001). Methyl jasmonate (MeJA) is the most common form of jasmonate used in treating CI, and occurs naturally in a wide range of higher plants. MeJA, usually applied as a vapour, has successfully reduced CI in many types of fresh produce, including mango (Gonzalez-Aguilar et al., 2001).

Salicylates act through similar pathways to jasmonates in initiating defensive responses to stress, including enhancing cell membrane integrity and promoting the release of heat-shock proteins (Aghdam and Bodbodak, 2013). Salicylates such as salicylic acid (SA) are found naturally in plant systems, and have shown benefits in reducing CI in many types of fresh produce, including mango (Barman and Asrey, 2014; Ding et al., 2007; Junmatong et al., 2015).

Oxalic acid (OA) is a natural antioxidant organic acid in plants and can reduce CI in mango fruit (Ding et al., 2007; Li et al., 2014). Research has also shown the potential of OA to inhibit browning in lychee (Zheng and Tian, 2006), and reduce CI in peach (Jin et al., 2014) and pomegranate (Sayyari et al., 2010).

The previous success of these natural plant compounds in reducing CI in mango, along with the association between USB and cool storage temperature, suggests that these treatments may also offer potential benefits in reducing USB. The current research aimed to explore the effectiveness of postharvest applications of MeJA, SA and OA in reducing USB in 'Honey Gold' mangoes.

Materials and Methods

Treatments

The trial was conducted at Fox Road, a commercial mango farm near Katherine (NT). 'Honey Gold' mango fruit were harvested at standard commercial maturity at around midday on 19th November 2015. Harvest from the Fox Road orchard is typically carried out at night to reduce USB. To obtain fruit with greater susceptibility to USB, experimental fruit were obtained from the commercial "clean-up" pick. This involved harvesting fruit remaining after the initial commercial harvest (mainly inside the canopy and with little blush) during the day. The treatments (Table 1) were each applied to 3 replicate trays containing 14 fruit. Each replicate treatment was applied at about 5 pm using a separate dip or fumigation container.

The fumigation treatment was carried out in 45 L plastic containers obtained from a local goods store. One tray of fruit was placed in each of the 3 replicate containers per treatment. Self-adhesive "draught-proofing" strips were applied around the rim of the container to provide an airtight seal, and the lid taped onto the container with duct tape to secure the seal. The fumigation concentrations were based on the free space in the container (that is, subtracting the fruit volume from the total container volume). The CO₂ concentration at the end of the 24 hour fumigation treatment was 4-5%, as measured with Kitegawa detector tubes.

The dip treatments were applied in 10 L water, with constant stirring to remove the boundary layer between the fruit and the water because of the fruit wax layer. The fruit were held at 20°C for the remaining 23 hours 50 min until the fumigation treatment was completed.

Table 1: Postharvest vapour and dip treatments applied at 20°C to 'Honey Gold' mangoes grown at Fox Road, near Katherine, Northern Territory.

Treatment	Details
Control	No treatment applied. Fruit held at 20°C for 24 h.
Vapour control	Fruit stored in a sealed container at 20°C for 24 h.
Dip control	Fruit dipped in water for 10 min, then held at 20°C for 24 h.
MeJA 0.01 mM	MeJA applied as a vapour at 0.01 mM (2.2 ppm) in a sealed container for 24 h.
MeJA 0.1 mM	MeJA applied as a vapour at 0.1 mM (22 ppm) in a sealed container for 24 h.
Salicylic acid	SA applied as a dip at 1 mM (0.138 gL ⁻¹) for 10 min, then held at 20°C for 24 h.
Oxalic acid	OA applied as a dip at 5 mM (0.630 gL ⁻¹) for 10 min, then held at 20°C for 24 h.

USB abrasion test

After the 24 h period of treatment, fruit were abraded using the USB test procedure. The fruit were abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial cold room set at 12°C for at least 6 days, then placed on a pallet near the rear of a refrigerated 20 pallet road trailer, and transported to Wamuran (South East Queensland; SEQ) at a set temperature of about 14°C. The fruit were transported by car to the Maroochy Research Facility (MRF), Nambour (SEQ) for assessment.

The fruit were ripened at 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly recorded.

USB areas were converted to a rating score of:

- 0 = none,
- 1 = up to 1 cm²,
- 2 = 1 to 3 cm²,
- 3 = 3 to 12 cm² (approx. 10%),
- 4 = >12 cm² (10%) and <25%,
- 5 = >25% of the fruit surface area affected.

Analysis

Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK), with the 'General Analysis of Variance' model used to analyse the data, with individual fruit as the experimental unit. The least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means.

Results and discussion

Under skin browning

Postharvest applications of MeJA vapour at 0.01 mM and OA as a dip significantly reduced the incidence of USB (% of fruit with USB greater than 1 cm²) (Table 2). These treatments resulted in 61.9% of fruit showing USB greater than 1 cm², while control treatments resulted in 80.5 to 82.5% of fruit affected. The 0.01 mM MeJA vapour and OA dip also significantly reduced the USB rating compared to the corresponding control treatments. Both MeJA treatments significantly reduced the severity of the resultant USB (the area of USB on affected fruit) when compared to the general control, but did not significantly differ to the vapour control. The OA dip resulted in reduced USB severity compared to both the general control and the dip control. In fruit with USB symptoms, the MeJA and OA treatments roughly halved the resultant area of USB compared to the control treatments.

Table 2: The USB incidence (percentage of fruit with USB >1cm²), rating (where 0 = none and 5 = more than 25% of the fruit area affected) and severity (USB area in affected fruit) in 'Honey Gold' mangoes treated by postharvest applications of methyl jasmonate (MeJA), salicylic acid and oxalic acid.

Treatment	Incidence of any USB > 1cm ² (%)	USB rating (0-5) for abrasion and background USB	Total USB area per fruit where USB occurred (cm ²)
Control	81.0 ^a	3.9 ^a	41.5 ^{ab}
Vapour control	82.5 ^a	3.1 ^{ab}	27.3 ^{bc}
MeJA 0.01mM vapour	61.9 ^b	2.3 ^c	15.3 ^c
MeJA 0.1mM vapour	65.1 ^{ab}	2.4 ^{bc}	16.9 ^c
Dip control	80.5 ^{ab}	3.4 ^a	47.0 ^a
Salicylic acid dip (1 mM)	83.3 ^a	3.5 ^a	42.5 ^{ab}
Oxalic acid dip (5 mM)	61.9 ^b	2.5 ^{bc}	22.3 ^c
Average LSD	18.8	0.8	16.4
Sample size	40-43	40-43	30-37

Data analysed by ANOVA, with individual fruit as the experimental unit. Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

USB incidence and severity did not significantly differ between 0.01 mM and 0.1 mM MeJA. In contrast, mangoes treated with MeJA at 0.1 mM have shown lower rates of CI than those treated at 0.01 mM (Gonzalez-Aguilar et al., 2001). Previous research suggested that the optimal concentration of MeJA to reduce CI may vary between commodities, and that application at high rates can have detrimental effects (Meir et al., 1996). In tomatoes, damaging effects occurred at concentrations greater than 0.01 mM MeJA (Ding et al., 2002).

The current trial suggests that the 0.01 mM MeJA and 5 mM OA were sufficient to elicit a beneficial reduction in USB, without the risk of detrimental effects. However, further experimentation to confirm these effects and to more precisely define the optimal rates for MeJA and OA, are warranted. Combination treatments could also be explored. For example, a possible synergistic effect in lemons was shown between salicylates and jasmonates, with a combined treatment of MeJA and SA showing greater reduction of CI than either treatment alone (Siboza et al., 2014).

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Effects of methyl jasmonate and oxalic acid on USB and ripening of 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Pip Bryant, Peter Hofman, Hung van Duong, Ted Winston,
Gavin Scurr

(2016/17)

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a superficial discolouration under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest, subsequent low temperature storage and vibration damage in transport.

Low storage temperatures after harvest increase USB, suggesting that treatments used to prevent chilling injury (CI) may be worth exploring as possible treatments for USB. Methyl jasmonate (MeJA) and oxalic acid (OA) are natural plant compounds that have shown signs of reducing chilling injury in mango. In a preliminary trial in the 2015/16 season these compounds showed some promise in reducing the incidence and severity of USB.

MeJA and OA were applied as postharvest vapour or dip treatments to 'Honey Gold' fruit harvested from two Northern Territory (NT) farms; Fox Road (Katherine) and Mataranka. Following treatment the fruit were abraded and then stored and transported at low temperature to encourage USB. Fruit were assessed for USB, skin colour and ripening.

The beneficial effects on USB observed in the previous season were not repeated, with MeJA and OA not significantly influencing USB incidence or severity. MeJA applied as a vapour did appear to accelerate fruit ripening, as shown by changes in skin colour and firmness. Higher concentrations of MeJA resulted in more rapid ripening, with 0.5 mM MeJA resulting in fruit ripening around 3 days earlier than the control. MeJA vapour treatment also showed the potential to increase the homogeneity of skin colour.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety is susceptible to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Under skin browning in 'Honey Gold' mango is more common when fruit are held below 14-16°C for at least 4-6 days. The fact that low storage temperatures exacerbate USB suggested that treatments used in the prevention of chilling injury (CI) may be worth exploring as potential treatments for USB. A literature review (separate report) identified the natural compounds methyl jasmonate (MeJA) and oxalic acid (OA) as potential preventative treatments for postharvest chilling injury in mango. A preliminary assessment of these potential treatments was undertaken in 2015/16. MeJA and OA treatments showed the potential to reduce USB incidence by around 20%. These treatments also roughly halved the resultant area of USB in fruit with the disorder.

In the 2016/17 season, the successful treatments trialled in the previous season were repeated, including MeJA applied as a vapour at concentrations of 0.01 and 0.1 mM, and OA applied as a dip. Additional treatments were also trialled in the 2016/17 season, including a higher concentration of MeJA to test for damaging effects, a shorter duration of MeJA exposure, the application of MeJA as a dip and the combination of MeJA with OA treatment. The postharvest treatments were applied to fruit from 2 different farms in the NT (Fox Road (Katherine) and Mataranka) to confirm whether the effects observed in 2015/16 were replicable across different seasons and farms.

Methyl jasmonate (MeJA) was also tested in the previous season for effects on blush development, and anecdotally was noted to result in more uniform, visually appealing trays of fruit. Similar effects have been observed on tomatoes, with greater homogeneity of colour and firmness shown in MeJA treated fruit (Baltazar et al., 2007). The effect has also been observed in 'Manila' mangoes, where colour change from green to yellow occurred more quickly and uniformly after treatment with MeJA (Herrera, 2004). The current trial will provide an additional opportunity to observe the effects of MeJA on homogeneity and ripening in 'Honey Gold' mangoes.

Materials and Methods

Treatments

MeJA and OA treatments (Table 1) were applied to 'Honey Gold' fruit from the Katherine area (Fox Road) and Mataranka, NT.

Table 1: Postharvest methyl jasmonate (MeJA) and oxalic acid (OA) treatments applied at 20°C to 'Honey Gold' mangoes grown in the Northern Territory.

Treatment	Details
Control	No treatment applied. Fruit held at 20°C for 24 h.
Vapour control (24h)	Fruit stored in a sealed container at 20°C for 24 h.
Vapour control (15h)	Fruit stored in a sealed container at 20°C for 15 h, then held at 20°C for 9 h.
Dip control (water)	Fruit dipped in water for 10 min, then held at 20°C for 24 h (OA dip control).
Dip control (water + Tween + ethanol)	Fruit dipped in water with 0.05% Tween 20 surfactant and 0.01% ethanol for 30 sec, then held at 20°C for 24 h (MeJA dip control).
MeJA 0.01 mM	MeJA applied as a vapour at 0.01 mM (2.2 ppm) in a sealed container at 20°C for 24 h.
MeJA 0.1 mM	MeJA applied as a vapour at 0.1 mM (22 ppm) in a sealed container at 20°C for 24 h.
MeJA 0.5 mM	MeJA applied as a vapour at 0.5 mM (110 ppm) in a sealed container at 20°C for 24 h.
MeJA (15 h)	MeJA applied as a vapour at 0.1 mM (22 ppm) in a sealed container at 20°C for 15 h, then held at 20°C for 9 h.
MeJA dip	MeJA applied as a dip at 0.1 mM (22 ppm) with 0.05% Tween 20 surfactant and 0.01% ethanol at 20°C for 30 sec (Droby et al., 1999; Meir et al., 1996; Shafiq et al., 2013), then held at 20°C for 24 h.
Oxalic acid	OA applied as a dip at 5 mM (0.63 gL ⁻¹) at 20°C for 10 min, then held at 20°C for 24 h.
Combined MeJA and OA	OA applied as a dip at 5 mM (0.63 gL ⁻¹) at 20°C for 10 min, followed by MeJA applied as a vapour at 0.1 mM (22 ppm) in a sealed container at 20°C for 24 h.

Fruit were harvested at standard commercial maturity in the early afternoon (12:30-1:30pm) and were de-sapped using mango wash. Fruit at Fox Road were harvested on 25th November, 2016, and at Mataranka on 4th December, 2016. After harvest, fruit were randomly assigned to treatment groups. Vapour treatments were applied by pipetting MeJA onto filter paper within a water-sealed plastic container. Each treatment was applied to 3 replicate trays of 14 fruit from each farm (totalling 42 fruit per treatment per farm), with replicate treatments applied in separate containers. A measurement of CO₂ in each container was taken by Kitegawa at the end of the treatment period to confirm an air-tight seal was maintained. The CO₂ concentration in containers ranged from 4 – 11.5%, tending to be higher in fruit from Mataranka, and higher with increasing MeJA exposure (Table 2).

Table 2: CO₂ levels in vapour treatment containers used to apply methyl jasmonate (MeJA) vapour to 'Honey Gold' mangoes.

Treatment	CO ₂ in container at end of treatment (%)	
	Fox Road	Mataranka
Vapour control (24h)	5.6 ^b	8.0 ^{bc}
Vapour control (14-16h)	4.5 ^c	6.3 ^d
MeJA 0.01 mM	5.6 ^b	8.0 ^c
MeJA 0.1 mM	6.1 ^{ab}	8.9 ^b
MeJA 0.5 mM	6.8 ^a	10.7 ^a
MeJA (15 h)	4.3 ^c	6.0 ^d
Combined (0.1 mM MeJA + OA)	5.8 ^b	8.6 ^{bc}
LSD	0.74	0.95

Data analysed by ANOVA, with replicate containers as the experimental unit (n=3). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

USB abrasion test

After the 24 h period of treatment, fruit were abraded by a standard procedure developed to promote USB. The fruit were abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc.

After abrasion, the fruit were randomised into trays for storage. The fruit were placed in a commercial cold room set at 12°C for at least 5 days, then placed on a pallet near the rear of a refrigerated road trailer, and transported to Wamuran, South East Queensland (SEQ) at a set temperature of 14°C. The fruit were transported by car to the Maroochy Research Facility (MRF), Nambour (SEQ), and were stored for up to 2 days at 16°C prior to initial assessment. After assessment, the fruit were treated with 10 ppm ethylene at 20°C for 3 days, and then stored at 20°C until near eating soft. Recorded temperature regimes are shown in Figure 1 (Fox Road) and Figure 2 (Mataranka).

Figure 1: Recorded storage temperature for 'Honey Gold' fruit harvested at Fox Road, Katherine, NT, and transported by refrigerated road freight to Wamuran, SEQ.

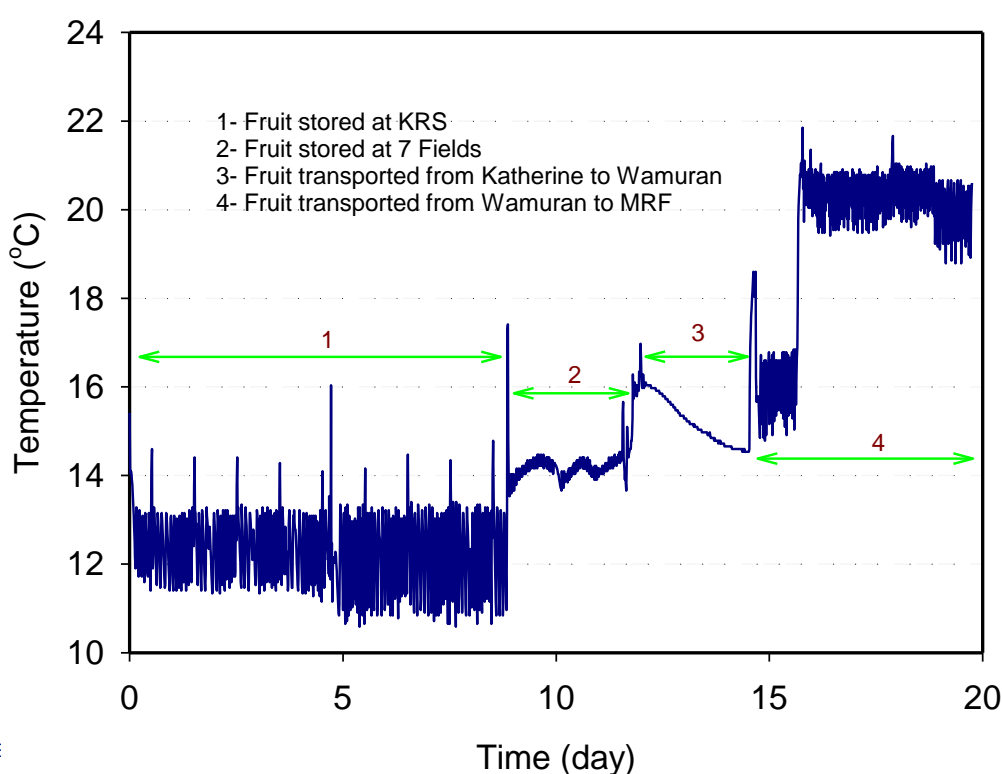
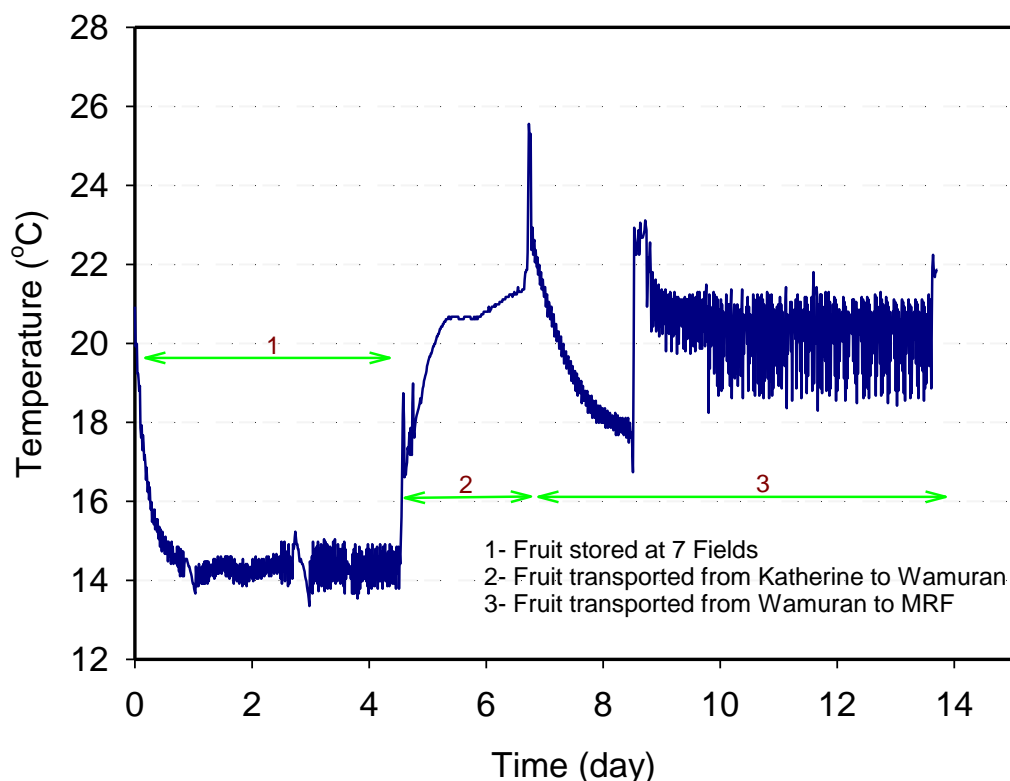


Figure 2: Recorded storage temperature for 'Honey Gold' fruit harvested at Mataranka, NT, and transported by refrigerated road freight to Wamuran, SEQ.



Assessment

Each fruit was marked with three numbered locations for background skin colour readings, not within the blush area or in blemished areas. Fruit were assessed upon arrival for skin colour and hand firmness, and Minolta colour readings were taken. Hand firmness (fruit softness) (0-4) was assessed according to the scale described in Holmes et al. (2010), where 0 = hard to 4 = soft.

Skin colour was assessed as the % surface area (%SA) of the whole fruit allocated to blush, yellow and green. These values were then used to determine skin colour and blush scores (1-6) as adapted from Holmes et al. (2010).

Skin colour rating scale

1	0-10% yellow
2	11-30% yellow
3	31-50% yellow
4	51-70% yellow
5	71-90% yellow
6	91-100% yellow

Blush rating scale

1	0-10% blush
2	11-30% blush
3	31-50% blush
4	51-70% blush
5	71-90% blush
6	91-100% blush

Minolta colour readings were taken at the 3 marked background sites and at the site of most intense blush colour.

An additional assessment was undertaken when most fruit were at or near eating ripe, 4-5 days after the initial assessment. Fruit were reassessed for skin colour, and Minolta colour readings were taken. Fruit were assessed for firmness using a Shimadzu EZ Test materials tester, EZ-SX, 100 N (Kyoto, Japan). Firmness was measured as the force in Newtons (N) required to push a 12 mm spherical probe to a depth of 2 mm into the fruit cheek at a rate of 10 mm min⁻¹. The fruit were also assessed for USB. For

each abrasion site with USB, the width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each calculated using the equation for an ellipse:

USB or Abrasion Area = $\pi \times A \times B$

Where A = the semi-major axis (0.5 x the longest diameter) and B = the semi-minor axis (0.5 x the diameter perpendicular to the longest diameter).

The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly estimated using the equation for an ellipse.

The number of days taken to reach eating ripe was estimated from firmness and colour score at the initial assessment and the assessment at day 4 or 5. Fruit assessed as softer or more yellow in skin colour at the initial assessment were proportionately weighted as ripening earlier (e.g. an initial firmness of 1 deducted 1 day, initial firmness of 2 deducted 2 days; Initial skin colour of 4,5 or 6 deducted 1,1.5 or 2 days, respectively, from total days to eating ripe). Conversely, for fruit not yet at eating ripe at the 4 or 5 day assessment, each 0.5 increment in firmness score or 1 unit increment of colour score added 1 extra day to the estimated 'days until eating ripe'.

Analysis

Statistical analyses were performed by Genstat® 14 for Windows™ (VSN International Ltd., UK). A 'General Analysis of Variance' model with blocking was used to analyse the data, with individual fruit as the experimental unit. Skin colour homogeneity within fruit was assessed by analysing the standard deviation of the 3 background skin measurements on each individual fruit. The least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means.

Results and discussion

Initial skin colour

MeJA vapour treatments strongly reduced green skin colour at the initial assessment, with higher concentrations of MeJA vapour resulting in a lower percentage of green skin (Table 3). The effect was significant at both farms, although much more strongly observed in the fruit from Mataranka. This result was also reflected in a correspondingly greater proportion of yellow skin colour in MeJA vapour treated fruit (data not shown), and in skin colour ratings (1-6, where higher numbers indicate more yellow skin). MeJA applied as a dip did not have the same effect on skin colour, with dipped fruit not significantly different to the control. The MeJA may have resulted in less green and more yellow skin colour through accelerated ripening.

Table 3: Effect of methyl jasmonate (MeJA) and oxalic acid (OA) postharvest treatments on 'Honey Gold' mango skin % green (% surface area coloured green) and skin colour rating (1-6, where higher numbers indicate more yellow skin) at initial assessment following transport from NT farms at Fox Road (Katherine) and Mataranka.

Treatment	Fox Road		Mataranka	
	% green	Rating (1-6)	% green	Rating (1-6)
Control	40.1 ^{abc}	2.8 ^{cd}	53.0 ^c	2.9 ^d
Vapour control (24h)	48.2 ^a	2.5 ^d	67.9 ^a	2.0 ^f
Vapour control (14-16h)	44.9 ^a	2.6 ^d	61.9 ^{abc}	2.3 ^{ef}
Dip control (water)	39.4 ^{abc}	3.0 ^{cd}	66.0 ^{ab}	2.3 ^{ef}
Dip control (water + Tween + ethanol)	39.5 ^{abc}	2.7 ^d	66.2 ^{ab}	1.9 ^f
MeJA 0.01 mM	33.0 ^{bcd}	3.4 ^{bc}	35.6 ^d	3.9 ^c
MeJA 0.1 mM	28.2 ^{def}	3.8 ^{ab}	15.6 ^{fg}	5.1 ^b
MeJA 0.5 mM	20.0 ^f	4.4 ^a	6.1 ^g	5.7 ^a
MeJA (15 h)	30.6 ^{cde}	3.9 ^{ab}	26.7 ^{de}	4.5 ^b
MeJA dip	41.3 ^{ab}	3.1 ^{cd}	60.6 ^{abc}	2.4 ^{def}
Oxalic acid	40.5 ^{ab}	2.8 ^d	57.1 ^{bc}	2.6 ^{de}
Combined (0.1 mM MeJA + OA)	22.1 ^{ef}	4.3 ^a	19.1 ^{ef}	4.9 ^b
LSD	9.59	0.61	9.96	0.58

Data analysed by ANOVA, with individual fruit as the experimental unit (n=42). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

The changes observed in skin colour due to MeJA treatment were also reflected in Minolta colour readings of the background skin colour at the initial assessment (Table 4). Fruit treated by MeJA vapour showed slightly lighter (higher L-value), more saturated (higher chroma value) skin colour, closer to yellow in hue, rather than green (hue typically changes from around 110 at green to 70 at yellow). The differences did not persist, and by day 5 the hue was only slightly more yellow in MeJA vapour treated fruit. The same trends were also shown in Fox Road fruit, although the effect was weaker (data not shown).

Table 4: Background skin colour changes in 'Honey Gold' mangoes from Mataranka, NT, in response to methyl jasmonate (MeJA) and oxalic acid (OA) postharvest treatments.

Treatment	Initial assessment			Day 5
	L-value	Chroma	Hue	Hue
Control	67.2 ^{bc}	45.2 ^d	95.1 ^d	78.0 ^{cd}
Vapour control (24h)	64.6 ^e	41.3 ^f	103.6 ^a	79.8 ^a
Vapour control (14-16h)	66.1 ^{cd}	42.7 ^{ef}	100.4 ^{abc}	78.3 ^{bcd}
Dip control (water)	65.1 ^{de}	41.8 ^{ef}	102.2 ^{ab}	78.9 ^{abc}
Dip control (water + Tween + ethanol)	64.9 ^{de}	42.6 ^{ef}	101.5 ^{ab}	79.1 ^{ab}
MeJA 0.01 mM	69.0 ^a	50.1 ^c	86.5 ^e	76.4 ^e
MeJA 0.1 mM	69.4 ^a	52.7 ^b	81.8 ^{fg}	75.6 ^{ef}
MeJA 0.5 mM	68.9 ^a	56.9 ^a	79.7 ^g	75.3 ^f
MeJA (15 h)	68.9 ^a	51.1 ^{bc}	85.5 ^{ef}	76.0 ^{ef}
MeJA dip	65.4 ^{de}	43.5 ^{de}	98.7 ^{bcd}	78.3 ^{bcd}
Oxalic acid	66.0 ^{cde}	42.7 ^{ef}	97.4 ^{cd}	77.9 ^d
Combined (0.1 mM MeJA + OA)	68.6 ^{ab}	51.2 ^{bc}	83.7 ^{ef}	76.1 ^{ef}
LSD	1.45	2.04	4.00	0.98

Data analysed by ANOVA, with individual fruit as the experimental unit (n=42). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Skin colour homogeneity

Mataranka fruit treated with MeJA vapour were more homogenous in colour at the initial assessment. The variation between fruit in hue and darkness of colour were significantly reduced by MeJA vapour (Table 5). This resulted in more uniform fruit colour across trays, as had been anecdotally observed in trials the previous season. Similar effects have been observed in previous trials on 'Manila' mangoes (Herrera, 2004) and tomatoes (Baltazar et al., 2007). The effect was not as strong in fruit grown at Fox Road, although showing the same trends (data not shown). As fruit ripened, the effect lessened, although the same trends persisted (data not shown). Greater homogeneity was also observed weakly in blush colour (data not shown) with slightly less variability of colour shown in MeJA vapour treated fruit.

Table 5: Homogeneity of skin colour between 'Honey Gold' fruit grown at Mataranka, NT, after postharvest treatment with methyl jasmonate (MeJA) and oxalic acid (OA), as assessed by standard deviation within replicate groups of fruit in skin darkness and hue at initial assessment.

Treatment	Standard deviation between fruit (within replicates)	
	L-value (darkness)	Hue angle (°)
Control	3.6 ^{ab}	11.8 ^a
Vapour control (24h)	3.6 ^{ab}	10.8 ^{ab}
Vapour control (14-16h)	3.1 ^{bc}	10.0 ^{ab}
Dip control (water)	4.4 ^a	11.1 ^{ab}
Dip control (water + Tween + ethanol)	3.3 ^{abc}	9.8 ^{ab}
MeJA 0.01 mM	2.7 ^{bcd}	7.9 ^{bc}
MeJA 0.1 mM	2.3 ^{cd}	4.5 ^{cd}
MeJA 0.5 mM	1.7 ^d	2.8 ^d
MeJA (15 h)	3.5 ^{abc}	9.6 ^{ab}
MeJA dip	4.3 ^a	11.0 ^{ab}
Oxalic acid	3.7 ^{ab}	9.8 ^{ab}
Combined (0.1 mM MeJA + OA)	2.4 ^{cd}	5.2 ^{cd}
LSD	1.22	0.95

Data analysed by ANOVA, with the standard deviation between average fruit values within each replicate group as the experimental unit (n=3). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Skin colour homogeneity within fruit was assessed by analysing the variability between the 3 background skin measurements on each individual fruit. While some slight effects were observed, these were not strong or consistent (data not shown).

Blush

No significant treatment effects were observed in the amount of blush (the percentage of blush on the skin or blush score) at either the initial or near eating ripe assessment (data not shown). The initial intensity of blush colour appeared to be slightly enhanced by the MeJA vapour treatments. At the initial assessment of Mataranka fruit, blush was slightly more saturated and more red-purple in colour in fruit treated with MeJA (Table 6). The response was strongest in the 0.5 mM MeJA treatment. This effect was not as evident in Fox Rd fruit, and lessened with ripening.

Table 6: Effect of methyl jasmonate (MeJA) and oxalic acid (OA) postharvest treatments on 'Honey Gold' mango blush colour at initial assessment, following transport from NT farms at Fox Road (Katherine) and Mataranka.

Treatment	Fox Road		Mataranka	
	Blush chroma	Blush hue	Blush chroma	Blush hue
Control	39.3 ^{bc}	66.3 ^{ab}	39.4 ^{ef}	74.7 ^{bcd}
Vapour control (24h)	39.2 ^c	68.8 ^a	39.4 ^{ef}	79.9 ^a
Vapour control (14-16h)	41.0 ^{abc}	69.3 ^a	39.8 ^{ef}	80.1 ^a
Dip control (water)	39.8 ^{bc}	64.3 ^b	41.5 ^{def}	77.1 ^{abc}
Dip control (water + Tween + ethanol)	40.3 ^{bc}	65.7 ^{ab}	38.6 ^f	78.7 ^{ab}
MeJA 0.01 mM	40.2 ^{bc}	64.2 ^b	43.5 ^{bcd}	72.7 ^{cde}
MeJA 0.1 mM	40.3 ^{bc}	62.7 ^b	44.9 ^{bcd}	68.8 ^{ef}
MeJA 0.5 mM	43.2 ^a	63.7 ^b	48.8 ^a	67.6 ^f
MeJA (15 h)	40.9 ^{bc}	66.4 ^{ab}	45.1 ^{bc}	73.3 ^{cde}
MeJA dip	41.2 ^{abc}	66.7 ^{ab}	42.3 ^{cde}	75.2 ^{abcd}
Oxalic acid	39.9 ^{bc}	66.3 ^{ab}	39.6 ^{ef}	75.5 ^{abcd}
Combined (0.1 mM MeJA + OA)	41.5 ^{ab}	62.6 ^b	45.8 ^{ab}	70.6 ^{def}
LSD	2.27	4.41	3.37	4.93

Data analysed by ANOVA, with individual fruit as the experimental unit (n=42). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Firmness and ripening

Fruit treated by MeJA vapour were softer at both the initial assessment (by hand firmness), and at day 4 or 5 assessment (tested by EZ tester) (Table 7). The effect was most pronounced in fruit treated with the highest level of MeJA. As was also shown in skin colour changes, the fruit at Mataranka showed a stronger response to the treatment than the Fox Road fruit. The firmness results are consistent with the hypothesis that MeJA caused more rapid ripening of the fruit.

Table 7: Firmness of 'Honey Gold' mangoes at initial assessment and near eating ripe after postharvest treatment with methyl jasmonate (MeJA) and oxalic acid (OA).

Treatment	Fox Road		Mataranka	
	Initial hand firmness (0-5)	Day 4 firmness EZ tester (N)	Initial hand firmness (0-5)	Day 5 firmness EZ tester (N)
Control	0.26 ^{cde}	5.4 ^{ab}	0.2 ^d	4.2 ^{cd}
Vapour control (24h)	0.17 ^e	5.6 ^a	0.0 ^d	4.6 ^a
Vapour control (14-16h)	0.21 ^{de}	5.2 ^{bc}	0.1 ^d	4.4 ^{abc}
Dip control (water)	0.29 ^{bcd}	5.2 ^{bcd}	0.1 ^d	4.5 ^{ab}
Dip control (water + Tween + ethanol)	0.38 ^{abcd}	5.1 ^{bcd}	0.1 ^d	4.3 ^{bcd}
MeJA 0.01 mM	0.45 ^{abc}	5.2 ^{bcd}	0.4 ^c	4.0 ^{de}
MeJA 0.1 mM	0.38 ^{abcd}	5.1 ^{bcd}	0.6 ^b	3.8 ^{ef}
MeJA 0.5 mM	0.52 ^a	4.9 ^{cd}	1.0 ^a	3.7 ^f
MeJA (15 h)	0.36 ^{abcde}	5.1 ^{bcd}	0.6 ^b	3.7 ^{ef}
MeJA dip	0.31 ^{bcd}	5.3 ^{ab}	0.2 ^d	4.4 ^{abc}
Oxalic acid	0.33 ^{abcde}	5.3 ^{ab}	0.1 ^d	4.4 ^{abc}
Combined (0.1 mM MeJA + OA)	0.48 ^{ab}	4.9 ^d	0.5 ^{bc}	3.7 ^{ef}
LSD	0.20	0.34	0.17	0.29

Data analysed by ANOVA, with individual fruit as the experimental unit (n=42). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Estimates of the time taken to reach eating ripe also suggest that the MeJA vapour treatments accelerated the ripening process (Table 8). The Mataranka control fruit typically took around 5 days from the initial assessment to reach eating ripe. In contrast, the 0.5 mM MeJA vapour treated fruit ripened in around 2 days. Accelerated ripening was also shown in Fox Road fruit, although to a lesser extent. The response appeared to be dose dependent, with higher concentrations of MeJA resulting in more rapid ripening. MeJA has similarly been shown to accelerate the ripening processes in 'Kensington Pride' mangoes (Lalel et al., 2003).

Table 8: Effect of methyl jasmonate (MeJA) and oxalic acid (OA) postharvest treatments on the estimated days taken to reach eating ripe (from the initial assessment) in 'Honey Gold' mangoes grown in the NT.

Treatment	Estimated days to eating ripe (days from initial assessment)	
	Fox Road	Mataranka
Control	5.1 ^{abc}	4.3 ^c
Vapour control (24h)	5.3 ^a	5.2 ^a
Vapour control (14-16h)	4.9 ^{bcde}	4.8 ^{ab}
Dip control (water)	4.9 ^{abcd}	4.8 ^{ab}
Dip control (water + Tween + ethanol)	5.0 ^{abcd}	5.0 ^{ab}
MeJA 0.01 mM	4.8 ^{bcde}	3.8 ^d
MeJA 0.1 mM	4.7 ^{def}	2.9 ^e
MeJA 0.5 mM	4.3 ^f	2.3 ^f
MeJA (15 h)	4.7 ^{cde}	3.2 ^e
MeJA dip	5.2 ^{ab}	4.6 ^{bc}
Oxalic acid	5.0 ^{abcd}	4.7 ^{bc}
Combined (0.1 mM MeJA + OA)	4.5 ^{ef}	3.1 ^e
LSD	0.38	0.41

Data analysed by ANOVA, with individual fruit as the experimental unit (n=42). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Under skin browning

The beneficial effects of MeJA on USB incidence and severity observed in the previous season were not evident in the 2016/17 season results. Fruit treated with MeJA or OA did not consistently differ from control fruit in the incidence or severity of USB (Table 9).

Table 9: Effects of postharvest treatment with methyl jasmonate (MeJA) and oxalic acid (OA) on the incidence and severity of USB in 'Honey Gold' mangoes grown in the NT.

Treatment	Fox Road		Mataranka	
	Incidence of any USB (%)	USB area per fruit where USB occurred (cm ²)	Incidence of any USB (%)	USB area per fruit where USB occurred (cm ²)
Control	50.0 ^d	24.1 ^{abc}	17	3.6 ^{abc}
Vapour control (24h)	73.8 ^{abc}	28.6 ^{ab}	33	2.3 ^{bc}
Vapour control (14-16h)	81.0 ^{ab}	22.9 ^{abc}	26	3.8 ^{ab}
Dip control (water)	50.0 ^d	32.3 ^a	19	1.0 ^c
Dip control (water + Tween + ethanol)	64.3 ^{bcd}	14.5 ^{cd}	19	5.9 ^a
MeJA 0.01 mM	85.5 ^a	24.7 ^{abc}	31	2.3 ^{bc}
MeJA 0.1 mM	76.2 ^{ab}	14.6 ^{cd}	14	0.7 ^c
MeJA 0.5 mM	61.9 ^{bcd}	10.4 ^d	19	1.4 ^{bc}
MeJA (15 h)	64.3 ^{bcd}	27.0 ^{ab}	12	2.1 ^{bc}
MeJA dip	54.8 ^{cd}	24.7 ^{abc}	12	1.6 ^{bc}
Oxalic acid	61.9 ^{bcd}	17.2 ^{bcd}	19	3.8 ^{abc}
Combined (0.1 mM MeJA + OA)	64.3 ^{bcd}	18.2 ^{bcd}	14	1.2 ^{bc}
LSD	20.01	12.07	17.00	2.97
Sample size	42	21-36	42	5-14

Data analysed by ANOVA, with individual fruit as the experimental unit. Means with the same letter within each column are not significantly different (at $p < 0.05$) as tested by LSD.

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Rootstock and soil effects on USB of 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Bhavisha Mehta, Philippa
Bryant, Gavin Scurr

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This publication has been compiled by Peter Hofman of AgriSciences Qld, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. It occurs primarily in fruit grown in the hotter production areas, especially the Northern Territory. Previous research indicated that fruit harvested in the afternoon were significantly more susceptible to USB than those harvested at night or in the morning. Also, two farms in the Katherine area of the Northern Territory produced fruit with differing susceptibility to USB over several years. Rootstock and soil type may contribute to varying fruit susceptibility to this disorder.

To test this hypothesis, a preliminary trial was conducted on a commercial farm in the Katherine area where trees were established on seedling 'Kensington Pride' rootstocks sourced from four known trees in the local area. The farm block was also established on two adjacent but different soil types, from a light sandy loam to a silty loam. At harvest, the fruit were lightly abraded at four points around the fruit with sandpaper, and then held at 12-14°C for about six days before commercial road transport to south-east Queensland.

The results suggested the potential for a rootstock effect on scion fruit susceptibility to USB, but there was no consistent effect of soil type on USB. There was little evidence of graft union incompatibility based on the ratio of rootstock: scion trunk diameter. Further testing of rootstock effects on existing, well documented sites may be justified.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma, small seed size and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Results over the last three seasons have consistently found that Honey Gold mango fruit from Dean's farm in Katherine are less susceptible to USB following abrasion, compared with fruit from Fox Road farm. These farms are about 15 km distant. Rootstocks can affect many aspects of fruit quality in other tree species. There is relatively little evidence of rootstock effects on physiological disorders of mango, however, given the evidence of this relationship in other fruit, it was considered worth investigating further. In addition comparisons were made between two different soil types on the same farm.

Materials and Methods

Treatments

The rootstock trial was conducted at Dean's, a commercial mango farm near Katherine (NT). This farm was established on seedling rootstocks with the seeds obtained from several known trees in the Katherine area. The location and history of these rootstocks were available. The rootstock sources are presented in Table 1. All datum trees were 10-12 years old and on the same sandy ridge (ex-river deposit). All of the rootstocks within each type came from a single tree, thus reducing genetic diversity within the one rootstock.

Table 1. Source of the 'Kensington Pride' rootstocks, and block and row of the datum trees on the Dean's farm.

Treatment	Rootstock	Location	Soil	Notes	Over/undergrowth
HK	Large 'Kensington Pride' tree near house on farm	Row 4 in block 1, trees 9-18	Sandy		Even or slightly smaller top
PC	Commons tree next to front gate on farm	Row 5, block 1, trees 9 -18	Sandy		Slight overgrowth on scion?
WC	Woodsie common ¹	Row 6, block 1, trees 9 -18	Sandy		Even
TER Sandy	Top End Rural ²	Row 29, trees 9-18, trees 9 -18	Sandy	Half the row is on sandy soil and the other half is on grey (more clay) soils	Basically even
TER Clay	Top End Rural ²	Row 29, trees 40-50	Grey, heavier clay		

¹Large high yielding tree on adjacent farm. Now cut down after 80 years

²Coloured turpentine common near Top End Rural store

Tree characteristics and fruit dry matter

Just before harvest the trunk diameter about 5 cm below and above the graft union was measured to estimate potential rootstock/scion incompatibility. The fruit number per tree before harvest was counted by two assessors, and the results averaged. The percentage dry matter of the flesh at harvest was determined by taking a portion of the cheek of each of 5 fruit per tree, grating and drying a subsample at about 60°C to constant weight.

USB abrasion test

One tray was harvested from each of five trees for each of the five treatments (total of 20 trays, with about 12 fruit per tray). The fruit were de-sapped in Mango Wash[®] and allowed to dry for about 2 hr. The fruit were then abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of five (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial 12°C-set cold room for at least six days, then placed on a pallet near the rear of a 20 pallet refrigerated road trailer, and transported to Wamuran (South East Queensland) at a set temperature of about 14°C.

The fruit were ripened at about 20°C with ethylene as required until near eating soft. The width and breadth of the abrasion, and of the USB lesion (including the abraded area) were measured separately, and the area of each calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Where required the areas were converted to a rating score of:

- 0 = nil,
- 1 = up to 1 cm²,
- 2 = 1 to 3cm²,
- 3 = 3 to 12cm² (10%),
- 4 = >12cm² (10%) and <25%,
- 5 = >25% of the fruit surface area affected.

USB was also observed on areas of the fruit that were not abraded with sandpaper. These were assumed to have been caused by normal commercial practices from packing onwards. These USB areas were also calculated as above.

Results and discussion

Tree characteristics and percentage dry matter

Table 2 indicates that TER rootstock on a sandy soil had higher dry matter than fruit from the other trees. There were minor differences in rootstock: scion diameter ratio but these did not suggest significant incompatibility between the rootstock and scion. There was no treatment effect on fruit number per tree at harvest (data not shown).

Table 2. The effect of 'Kensington Pride' rootstock and soil type on 'Honey Gold' mango percent dry matter at harvest and rootstock and scion trunk diameter and its ratio.

Treatment	Flesh % dry matter	Root diameter (cm)	Scion diameter (cm)	Scion: rootstock diameter ratio
HK Sandy	16.5 ^e	64.2 ^a	58.1 ^{bc}	0.90 ^c
PC Sandy	18.6 ^c	58.5 ^b	62.9 ^a	1.08 ^b
WC Sandy	17.3 ^d	55.0 ^b	62.1 ^{ab}	1.13 ^a
TER Sandy	19.4 ^a	58.0 ^b	51.8 ^d	0.89 ^c
TER Grey	18.9 ^b	63.1 ^a	55.8 ^{cd}	0.89 ^c

Under skin browning

The four different rootstock treatments on sandy soil showed significant differences in USB development, with the WC rootstock showing lower incidence of USB on abrasion sites compared with PC, and on non-abrasion sites compared with HK and TER rootstock (Table 3). There was no consistent rootstock effect on USB severity.

The comparison of TER rootstock trees grown on different soil types suggested that the incidence of USB around abrasion sites was significantly higher in fruit grown on sandy soil, but there were no soil effects on incidence at non-abrasion sites and in severity.

The results suggest the potential for rootstock effects on USB, but little consistent effects of the soils tested.

Table 3. The effect of 'Kensington Pride' rootstock and soil type on USB development in 'Honey Gold' mango fruit harvested from Dean's farm. Means with the same letter are not statistically different ($P=0.05$).

Treatment	% of abrasion sites with USB	USB severity rating (1-5) of		% of fruit with USB >1 cm ² at non-abrasion sites
		Abrasion sites with USB	Non-abrasion USB for fruit with non-abrasion USB	
HK Sandy	8.9 ^{bc}	3.8 ^a	2.9 ^{ab}	58.5 ^a
PC Sandy	20.2 ^a	2.8 ^b	2.6 ^b	47.4 ^{ab}
WC Sandy	9.4 ^{bc}	3.4 ^{ab}	2.4 ^b	35.4 ^b
TER Sandy	13.5 ^{ab}	3.6 ^a	2.7 ^b	55.8 ^a
TER Grey	4.9 ^c	3.8 ^a	3.3 ^a	62.5 ^a

Photon effects on USB of 'Honey Gold' mango

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Peter Hofman, Ted Winston, Pip Bryant, Gavin Scurr

(2015/16)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mango fruit are susceptible to under skin browning (USB), a bruise-like symptom just under the skin that does not affect flesh quality. Previous research has established that USB is associated with hot growing conditions, high temperature at the time of harvest and subsequent low temperature storage and vibration damage in transport.

Photon™ 500 SG, applied as a foliar spray, is commercially marketed for reducing the impact of environmental stress in fruit crops. Given the association of USB with high temperature stress at harvest, a preliminary trial was considered worthwhile to assess the potential benefits of this treatment.

In an exploratory trial, Photon was applied to entire blocks of the orchard by repeated foliar sprays throughout the growing season, with and without Screen™ (a reflectant spray to reduce heat stress from incident radiation) and by fertigation. A control block was intended to receive no Photon treatment, but was inadvertently sprayed once with Photon. Hence, an additional control group was harvested. These trees had been treated with Crop-Set®, which was not applied to the other treatments.

After harvest the fruit were lightly abraded at four points around the fruit with sandpaper, then held at 12-14°C for about six days before commercial road transport to south-east Queensland. When near eating ripe, the fruit were assessed for USB. Packhouse packout data was also obtained to assess impacts under commercial procedures.

There were no important treatment effects on USB, with all fruit showing similarly high incidence of USB. The commercial packout data suggested a reduced proportion of fruit in bulk and increased proportion in Class 1 and 2 with Photon treatment. Also, all treatments reduced the proportion of fruit in count 16 and increased the proportion in count 12, compared with the control. Further trials are recommended to confirm the benefits of Photon on fruit size and packouts, but further research on USB effects is not recommended.

Introduction

The 'Honey Gold' mango variety, selected in Australia in 1991, combines the appealing characteristics of attractive colour, flavour, texture and aroma and good shelf life. However, the variety has shown susceptibility to under skin browning (USB), characterised by opaque superficial discolouration just under the skin surface. The disorder has been observed most commonly in fruit grown under hot conditions and subsequently transported by road freight at low temperatures.

Photon™ 500 SG is commercially marketed as a foliar spray treatment to reduce the impact of environmental stress in fruit crops. The product is comprised of a blend of dicarboxylic acids (500 g/kg) that occur naturally in plants. It is described as having a systemic effect, triggering a biochemical response in plants that enhances protection against abiotic stresses, such as excessive light, heat and drought.

Photon was used commercially at Fox Road in 2014, and USB incidence was markedly less in this season compared to previous seasons. However, there were no untreated trees for comparison, and most harvesting in this season was undertaken at night, which trials have shown reduces USB significantly. Dean's farm had more USB in 2014 than in previous years, with daytime harvest and no use of Photon. In contrast, Hayes farm combined daytime harvest with Photon application and had a lower incidence of USB. A preliminary Photon trial was warranted, given the association of USB with high temperature stress at harvest, and some anecdotal evidence of reduced USB with Photon application.

Materials and Methods

Treatments

The Photon trial was conducted at Fox Road, a commercial mango farm near Katherine, Northern Territory (NT). The Photon™ 500 SG treatments were each applied to an orchard block as shown in Table 1.

Table 1: Photon™ 500 SG treatments applied to blocks of 'Honey Gold' mangoes at Fox Road, Katherine, Northern Territory (NT).

Treatment	Details
1: Control*	
2: Crop-Set control	Crop-Set® was applied at the commercial rate.
3: Screen + Photon spray	Screen™ was applied at the commercial rate of 2.5% in mid-July with a repeat spray after 14 days and then Photon every 21 days at 30 g ha ⁻¹ until harvest.
4: Photon spray only	Photon was applied as a foliar spray every 21 days at 30 g ha ⁻¹ from mid-July until harvest.
5: Photon fertigation	Photon was applied by fertigation every 21 days at 40 g ha ⁻¹ from mid-July until harvest.

*The control treatment inadvertently received a single application of Photon in early October. The Crop-Set control did not have any Photon applied, and was treated with Crop-Set, which was not applied to other treatment groups. This additional control was on a more mature block of trees.

USB abrasion test

Fruit were harvested at standard commercial maturity, on 16th November 2015, with harvest commencing at approximately 2pm. Three sample rows were selected, with at least one row between each sample row. A total of 16 fruit were harvested from each sample row, with 1-2 fruit harvested from each of 10 trees. The fruit were de-sapped in Mango Wash® for about 2 minutes and allowed to dry for approximately 2 hours. The fruit were then abraded at four locations around the largest circumference of the fruit using a small orbital finishing sander (Ozito model OZDS280WA) at a speed setting of 5 (on a scale of 1-6), using 60-80 grit sandpaper, and with about 110 g of pressure at the sanding disc. The fruit were then placed in a commercial 12°C-set cold room for at least 6 days, then placed on a pallet near the rear of a refrigerated road trailer, and transported to Wamuran, South East Queensland (SEQ) at a set temperature of 14°C. The fruit were transported by car to Maroochy Research Facility (MRF), Nambour (SEQ) for assessment.

The fruit were treated with ethylene as required then held at 20°C until near eating soft. The width and breadth of the abrasion, and of any USB discolouration (including the abraded area) were measured separately, and the area of each calculated by using the equation for an ellipse. The USB area was then calculated by subtracting the abrasion area from the combined USB + abrasion area. Any background USB, occurring separately from the abrasion sites, was also similarly recorded.

Packout and quality

Packhouse packout data (7 Fields Packhouse, Katherine) were obtained for each of the treatment blocks for total yield, yield per grade and yield per fruit size (count).

Statistical analysis

The experiment was carried out as an exploratory, semi-commercial trial, in order to obtain commercial packout data and with a view to further research if results were promising. The data have not been statistically analysed, but are presented as mean values with standard error.

Results and discussion

Under skin browning

The Photon treatments did not appear to result in any beneficial reductions in USB compared to the control and Crop-Set control (**Figure 1**). The incidence of USB was consistently high in the trial, ranging from 87-98%, with little consistent difference between treatments. Similarly, the total area of USB in fruit with the disorder did not show a strong treatment response, and was lowest in the control. The results of this exploratory trial do not support further experimentation with Photon for the prevention of USB.

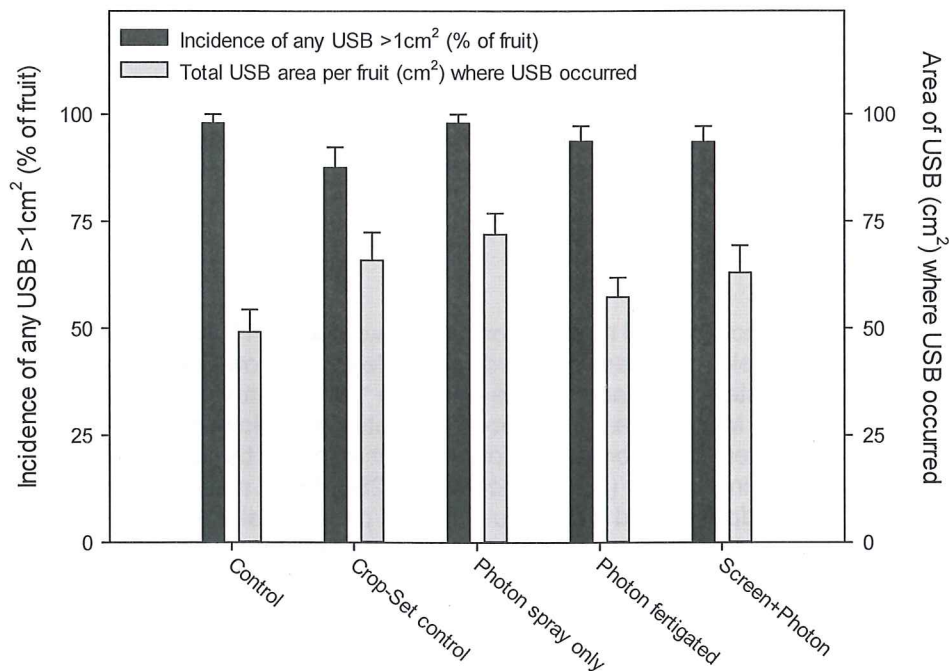


Figure 1: Various Photon™ treatment effects on under skin browning on ripe ‘Honey Gold’ mango following abrasion at four locations on the fruit, then holding at about 12°C before ripening and assessment. Control fruit received one accidental Photon™ spray, while Crop-Set® control trees received no Photon™, and other treatments received repeated applications every 21 days. The area of USB per fruit was based on only those fruit that developed USB. Bars show standard error. (n=42-48 fruit per treatment.)

Packout and quality

The control treatment showed the highest proportion of fruit in bulk and juice grades, at 18.2%, while the Photon spray treatments resulted in only 6.5-8.7% of fruit weight in these grades, and increased proportions of fruit in Class 1 and 2 (Table 2). Hence the Photon spray and Photon + Screen sprays appeared to slightly improve the overall quality of fruit at packout, but further trials with replication would be required to confirm these effects.

The Crop-Set control appeared to result in higher overall yield and a lower proportion of premium fruit, with 52.6% premium packout compared to 64.7 to 66.6% in other treatments. This may be a result of the more mature trees in this additional control treatment.

Table 2: Effect of photon treatments on the packout data for 'Honey Gold' mangoes, including weight and percentage (by weight) of fruit in each class.

Treatment	Premium	Class 1	Class 2	Bulk	Juice	Total
Weight in each class (kg)						
Control*	19,418	4,417	5	4,510	800	29,150
Crop-Set control	20,223	12,565	959	4,680	0	38,427
Photon spray only	17,829	6,398	963	1,760	0	26,950
Photon fertigation	18,018	5,985	756	3,085	0	27,844
Screen + Photon	16,989	6,083	221	2,245	200	25,738
% in each class (by weight)						
Control*	66.6	15.2	0.0	15.5	2.7	
Crop-Set control	52.6	32.7	2.5	12.2	0.0	
Photon spray only	66.2	23.7	3.6	6.5	0.0	
Photon fertigation	64.7	21.5	2.7	11.1	0.0	
Screen + Photon	66.0	23.6	0.9	8.7	0.8	

*Control fruit inadvertently received a single application of Photon.

The control treatment appeared to have a lower percentage of large sized fruit than the Photon treatments and Crop-Set control (

Figure 2). Counts 8-10 comprised 4% of the control fruit by weight, while for the Photon spray treatment, 11.3% of fruit by weight were in this larger size bracket. In contrast, the control fruit showed more medium-sized fruit, particularly size 16 count fruit (24.3% of control fruit weight) compared to the other treatments (15.8 to 17.9%). This indicates increased fruit size associated with the Photon/Screen treatments.

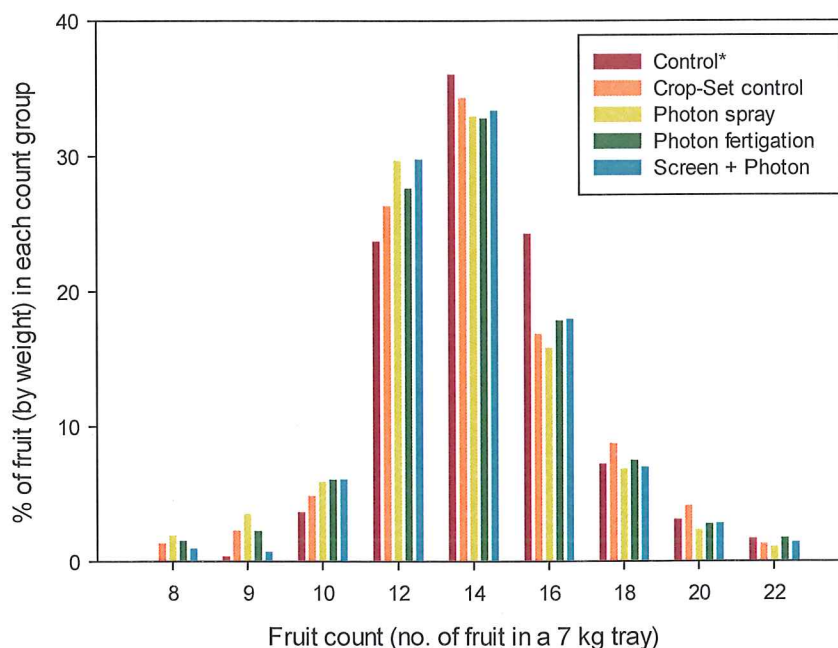




Figure 2: The effect of Photon™ treatments on the percentage of 'Honey Gold' fruit (by weight) in each size count (number of fruit in a 7 kg tray), obtained from packout data.

Conclusions

This trial was conducted under semi-commercial conditions without treatment replication. However, the results suggest little treatment effect on USB, but potential benefits in relation to reduced percentage of fruit in bulk and increased percentage in Class 1-2 fruit. The increase in the percentage of larger sized fruit may have possible negative commercial impacts, which would need to be evaluated using tools such as benefit cost analysis.

These treatments should be repeated over several seasons (replications) to confirm treatment effects and commercial benefit.



Lenticel damage on ‘Honey Gold’ mango with special reference to red lenticel

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Peter Hofman, Ted Winston, Bhavisha Mehta, Philippa
Bryant, Gavin Scurr

(2014/15)



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Summary

'Honey Gold' mango fruit can develop red halos around the lenticels (called red lenticel), especially in production areas south of Rockhampton, and particularly following significant rain during the last three or four weeks before harvest. Other forms of unattractive red pigment accumulation on the ripe fruit have been observed, particularly in a farm in northern New South Wales. The commercial impact of these symptoms could be reduced by either increasing overall red blush of the fruit or reducing the stress factors (most likely associated with water entry into lenticels) that appears to trigger red pigment production. Preliminary trials this season investigated some of these options.

Descriptions of the three main types of lenticel on 'Honey Gold' were developed to reduce confusion and provide consistent diagnosis. The significance of pepper spot (most likely localised anthracnose infections) and sun bleaching on red halos were defined. Control mechanisms for pepper spot and sun bleaching are well understood and will not be investigated further in this project, except for spray treatments to minimise sun bleach by reducing the stress response to excessive radiation.

A trial conducted on a commercial 'Honey Gold' farm at Wamuran applied sucrose, fructose and Ethrel[®] (ethylene releasing agent) dips to fruit on trees in an attempt to increase red blush, and paper bags and ReTain[®] (anti-ethylene), to reduce blush. The bags were applied about four weeks before harvest, and the sprays applied roughly every five days on four occasions before harvest. Water plus Agral (wetting agent) and/or spray treatments increased the percentage area with blush on the ripe fruit but the increase was relatively small (estimated at about 10%), and did not affect the intensity of the blush colour at ripe. Exposure of fruit to blue light from harvest to ripe had little effect on blush area intensity and area.

Applications of Raingard[®] and a carnauba- based postharvest wax aimed at minimising rain contact with fruit, showed an 8% reduction in the percentage of red lenticels compared with control. Commercial fruit bags applied about four weeks before harvest reduced the percentage of red lenticels by about 17% compared to the control. This indicates the potential for Raingard[®] and bagging to reduce red lenticel, although there was no significant effect on lenticel damage or red lenticel severity in this trial.

Treatment with 0, 20, 120 and 500 ppm ethylene for three days at 20°C at the start of ripening indicated that ethylene can increase red lenticel severity at ripe compared with control. Ethylene treatment also increased the red colour of the blush area. These effects were relatively small and likely to have negligible commercial impact with good ripening practice. However, under wetter production/harvest conditions the ethylene response may well be stronger.

The trials this season provided several leads for further development. These include ethylene and sugars treatments to increase blush, and Raingard and bagging to reduce rain effects on red lenticel. These treatments will be investigated in future seasons, possibly in combination with environment-manipulating practices to stimulate expression, such as overhead irrigation on treatment trees and plastic coverings over trellised mangoes.

Introduction

'Honey Gold' mango grown in the cooler and wetter areas of central and southern Queensland (SQ) and northern New South Wales (nNSW) as compared with Northern Territory and North Queensland (NQ), often develop red halos around their lenticels during significant rain in the weeks leading up to harvest. In severe cases, red streaks develop on parts of the fruit, possibly where rain frequently runs down the fruit. Also, fruit grown in some areas, especially nNSW, can develop quite extensive areas of red and dark red discolouration on the skin surface. It is not known what causes this discolouration and to what extent they may be a more pronounced form of red lenticels. In both cases, affected fruit are downgraded or rejected. In contrast, 'Honey Gold' fruit are relatively resistant to the widespread form of brown-black lenticel damage seen in other mango cultivars during and after harvesting and postharvest treatments.

Commercial experience suggests that red lenticel in 'Honey Gold' is more problematic on farms from Rockhampton south. Up to half the fruit can be affected to varying degrees, seemingly based on how much rain occurs during mid-late fruit growth. Badly affected fruit are downgraded to juice, but more commonly are downgraded from premium to class 1. Losses can be significantly greater in some years, especially when there are significant volumes of fruit harvested in February and March.

Lenticel damage on mango fruit can seriously affect visual appearance. Symptoms can be categorised into:

- lenticel spotting, which may develop via entry of water into the lenticel and the subsequent collapse and discolouration of adjacent cells (Rymbai et al., 2012).
- lenticel discolouration, which involves a halo of coloured skin around the lenticel, with or without a lenticel spot in the middle (Bezuidenhout, 2005; du Plooy, 2006). The halo can be red or dark brown, and it is possible that the brown halo is a more advanced stage of red pigment development or from a darker background skin colour (Rymbai et al., 2012). However, green halos around lenticels have also been observed, suggesting interesting fruit skin colour responses to external stimuli.

Lenticel damage in 'Calypso™' (the most sensitive of the main Australian cultivars) appears to be caused by damage and collapse of the cells close to the lenticels, resulting in lenticel spot. It mainly develops after harvest, and severity increases with water contact during harvesting and packing, and significantly after irradiation. Red lenticel is rare in this cultivar.

Pre- and postharvest operations can affect lenticel discolouration. Severe lenticel spotting of several South African cultivars was positively correlated with high humidity and rainy conditions at harvest (Oosthuysen, 1998). This relates well to the 'Honey Gold' observations of more severe red lenticel with rainy periods before harvest. Lenticel discolouration has occurred in NQ on several occasions following use of foliar fertilizers, especially what was thought to be high K foliar sprays after previous copper sprays where residues of earlier copper sprays may have remained in the lenticel.

Several postharvest practices can reduce red lenticel in 'Tommy Atkins' mango, including one day delay between picking and packing (Cronje, 2009a), not dipping fruit in de-sapping solution (calcium hydroxide) (Self et al., 2006), and dipping fruit before packing in salt solution for two or five minutes (Cronje, 2009b).

Red halos around lenticels likely involve the synthesis of plant pigments such as anthocyanins in sub-lenticellular cells (Dixon and Paiva, 1995; du Plooy et al., 2009), possibly a plant response associated with some form of stress in the cells. It is not clear what regulates pigments in these instances; it may reflect changes in cell water potential or pH caused by water or de-sapping solution entering the lenticels (Self et al., 2006). The red discolouration appears to be more common on the sun-exposed parts of the fruit where the tissue has been "primed" by this exposure, and the additional stress from e.g. water entering the lenticels is the trigger to finish the process and produce red pigments.

There are two potential approaches to addressing red lenticel. Increasing the red colour of the fruit may mask additional red pigmentation around the lenticels, while minimising red lenticel development, which commercial observations suggest may be associated with rain) could reduce the development of red lenticels. MG13016 planned to undertake lab-based trials in the first season to identify treatments that could be tested in the field in later seasons. However a literature review suggested that the manipulation of red blush may require a number of weeks of treatment before harvest. Hence, field trials were undertaken this season.

Several other suggestions on causes of red skin have been made over the last few years. Commercial observations in nNSW suggested that red skin damage can occur when the small on-farm ripening room was full of ripening mangoes, and there was an obvious “mango ripening” odour. It was suggested that the volatiles from mango sap and ripening fruit may contribute to red skin. Also, when the USB abrasion test was applied to the blushed area of fruit from NQ, the USB that develops can be a dark purple because of the brown/red colour interaction, and possibly because of an often observed increase in red pigment around abrasion points. These possibilities were also tested in very small trials with fruit from nNSW.

The preliminary trials this year focussed on:

- Classifying the main types of lenticel damage to ensure common diagnosis
- Pre-harvest (sugars and ethylene “regulators”) and postharvest treatments (picking and packing practices, ethylene and blue light) to increase red pigment production
- Interactions with skin damage/abrasion and ripening fruit volatiles

Materials and Methods

Lenticel survey and classification

Reports and concerns about red lenticel in NQ, and potential misdiagnosis, resulted in a survey of several Atherton Tablelands farms to identify and classify the main types of lenticel damage, to provide names for the lenticel types, and to refine what types of lenticel damage this project would focus on.

Increasing red blush

This trial was conducted on a commercial ‘Honey Gold’ farm at Wamuran, and aimed to manipulate the degree of blush on the fruit. The following treatments were applied to one fruit on each of 20 trees (seven treated fruit per tree).

1. Control – no treatment
2. Control, water + 0.2% Agral.
3. Fruit bagging with white paper bags.
4. 10% fructose + 0.2% Agral at roughly five day intervals, and repeated four times before harvest.
5. 10% sucrose + 0.2% Agral, as above.
6. Ethrel® (Bayer; 720 g.L⁻¹ Ethephon); 2 mL.L⁻¹ with 0.2% Agral.
7. ReTain® (Aminoethoxyvinylglycine; AVG; 150 g.kg⁻¹); 0.83 g.L⁻¹ with 0.2% Agral.

Treatments 2 and 4-7 were applied by dipping the fruit in the relevant treatment solutions for one minute. The first treatment was applied early February, and repeated at 5-6 day intervals for a total of four treatments. The fruit were harvested five days after the last treatment.

The fruit were harvested in a dipped solution of Sportak then ripened at 20°C (no ethylene). Ten fruit per treatment were placed under blue LED lights during the whole of the ripening period. The fruit were turned and randomised every 2-3 days.

Reducing rain contact with fruit

A commercial orchard at Yelgun was used because of ongoing challenges with red lenticel and red/purple skin discolouration at this farm. The following treatments were applied to one fruit on each of 20 trees (six treated fruit per tree).

1. Control (no treatment).
2. Water.
3. Raynox at 5% in tank water (no water softener required).
4. Raingard at 5% in tank water.
5. Natural Shine, 10% with 0.1% of 1020 g/l polyether modified polysiloxane, (Sumitomo Chemical Australia Pty Ltd).
6. Bagging using commercial paper bags designed specifically for fruit bagging (purchased from Fernland Nurseries, Nambour). Fruit bagged at about 4 weeks before harvest.

Raynox (supplied by Collin Campbell Chemicals (<http://www.campbellchemicals.com.au/raynox-resource>) is used as a sunburn protectant in apples but may help reduce water contact with the fruit skin. RainGard is applied as a protective film on cherries to decrease uptake of rain water by the fruit. RainGard™ (supplied by Collin Campbell Chemicals (<http://www.campbellchemicals.com.au/kcfinder/upload/files/RainGard%20May%202011.pdf>) is used primarily to prevent skin splitting in cherries by maintaining the integrity of the skin, thereby reducing water uptake. Natural Shine is a postharvest wax used to prolong storage life in mango. Pre-harvest trials with 'Calypso' indicated a potential to reduce lenticel spotting at ripe, presumably by reducing the negative effects of water entry into lenticels.

With treatments 2-5 the fruit were sprayed to runoff using a small domestic spray applicator. The treatments were applied approximately every week thereafter for a total of four applications.

All fruit were harvested about five days after the last treatment, de-sapped by dipping in Mango Wash® for two minutes, taken to the postharvest laboratories at Maroochy Research Facility, Nambour, dipped in Sportak®, then treated for two days with 10 ppm ethylene at 20°C and ripened at 20°C. Quality was assessed as described below.

Ethylene and red skin colour

'Honey Gold' mango fruit were obtained from the same Yelgun farm. About 200 fruit were harvested from about 40 trees to provide 24 fruit (two trays) per treatment/replication. Fruit were harvested from three areas of the same management block on 6th February.

All fruit were harvested with long stems. Half the fruit were de-sapped without Mango Wash or water, and given no other packhouse treatment. The other fruit were de-sapped by dipping for two minutes in Mango Wash, and then placed over a commercial packing line that included brushing and fungicide treatment (called commercial practice; CP). Fourteen fruit from each of the no CP and CP treatments were treated with zero, ~20, ~120 and ~450 ppm ethylene for three days.

The 0 ppm fruit were held in a standard coldroom; the 20 ppm fruit were held in a small ripening room, and the 120 and 450 ppm fruit placed in 1 m³ enclosures. Ethylene concentrations were controlled with ethylene sensors attached to an RC3.8 controller (CRS Australia). The desired concentrations were 20, 100 and 500 ppm but these were not achieved because of poor sensor performance.

After three days ethylene treatment the fruit were placed in a 20°C ripening room and assessed about three times during ripening.

Sap volatiles and USB abrasion test

The effects of several other factors were tested in very preliminary trials with fruit from the Yelgun farm.

Two trays (about 30 fruit) were harvested and the sap from all fruit collected. The two trays were placed inside LDPE bags (about 50µm). With one of the bags the sap was placed in a petri dish inside the bag to increase the concentration of sap volatiles around the fruit. Both bags had about six holes made with a hypodermic needle to reduce carbon dioxide build-up in the bags. The fruit were held at 20°C for about 10 days and assessed at ripe.

An additional tray of fruit (about 12 fruit) were treated using a USB abrasion test by lightly abrading the skin for two seconds then placing the fruit at 12°C for about six days before ripening at 20°C. Another tray of fruit was not abraded but held under the same temperature conditions. The incidence of under skin browning was assessed at the ripe fruit stage.

Quality assessment

The % blush was rated as 1 = 0 - 10%, 2 = 10% - 30%, 3 = 30% - 50%, 4 = 50% - 70%, 5 = 70% - 90%, 6 = 90% - 100% of the skin area with blush. The intensity of the blush colour was quantified with a Minolta colour meter by taking 2-3 representative readings on the blush portion of the fruit

Total lenticel severity and red lenticel severity was rated on a 1-6 scale based on Hofman et al. (2010). In several trials, two circles of 2.5 cm² were drawn at locations of the fruit with typical lenticel symptoms (usually around the shoulders and the largest circumference of the fruit). The number of white, black and

pink/red lenticels within each circle was counted, and the results presented as the number of lenticels per cm^2 and as the percentage of white, black and red lenticels relative to the total number of lenticels.

Fruit firmness was rated by hand on a scale of 1 = firm and 4 = soft ripe (eating soft for 'Honey Gold' mango). The days to eating soft were the number of days from harvest when the fruit reached a firmness of 4.

Statistical analysis

For the "Increasing red blush" trial, 20 individual fruit replications (one fruit from each of 20 trees) were used. The results were analysed as a factorial (seven field treatments by two post-harvest treatments of -/+ blue light). There were few interactions between field and blue light treatments so the main effects were generally presented. For the "Reducing rain contact with fruit", each treatment was applied to one fruit on each of 20 trees to provide 20 individual fruit replications. The results were analysed using a general analysis of variance model. For "ethylene and red skin colour", 24 fruit were harvested from three separate locations in the same orchard. In most cases the results were analysed using single fruit replications as a factorial design of four ethylene concentrations by -/+ commercial harvesting and packing. All analyses were performed with GenStat.

Results and discussion

Lenticel types and red skin damage

Observations of fruit from commercial farms in NQ suggested three main lenticel "types" (Plate 1):

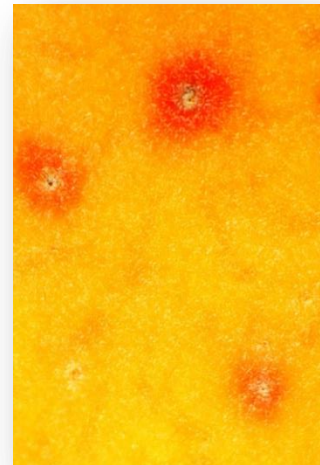
1. White lenticel. These are "healthy" lenticels with no visible damage or pigmentation to the surrounding cells
2. Black lenticel (or lenticel spot). Pigmentation or cell death has occurred in the cells around the lenticel opening. The extent of the damage can vary, and can be more obvious or severe on the areas of the fruit that were bleached from excessive sun exposure.
3. Red lenticel, where there was a distinct red halo around the lenticel. In these instances, it is assumed some form of stress (for example water entry) stimulated a defence reaction in the cells surrounding the lenticel cavity, resulting in red pigment production.



White lenticel



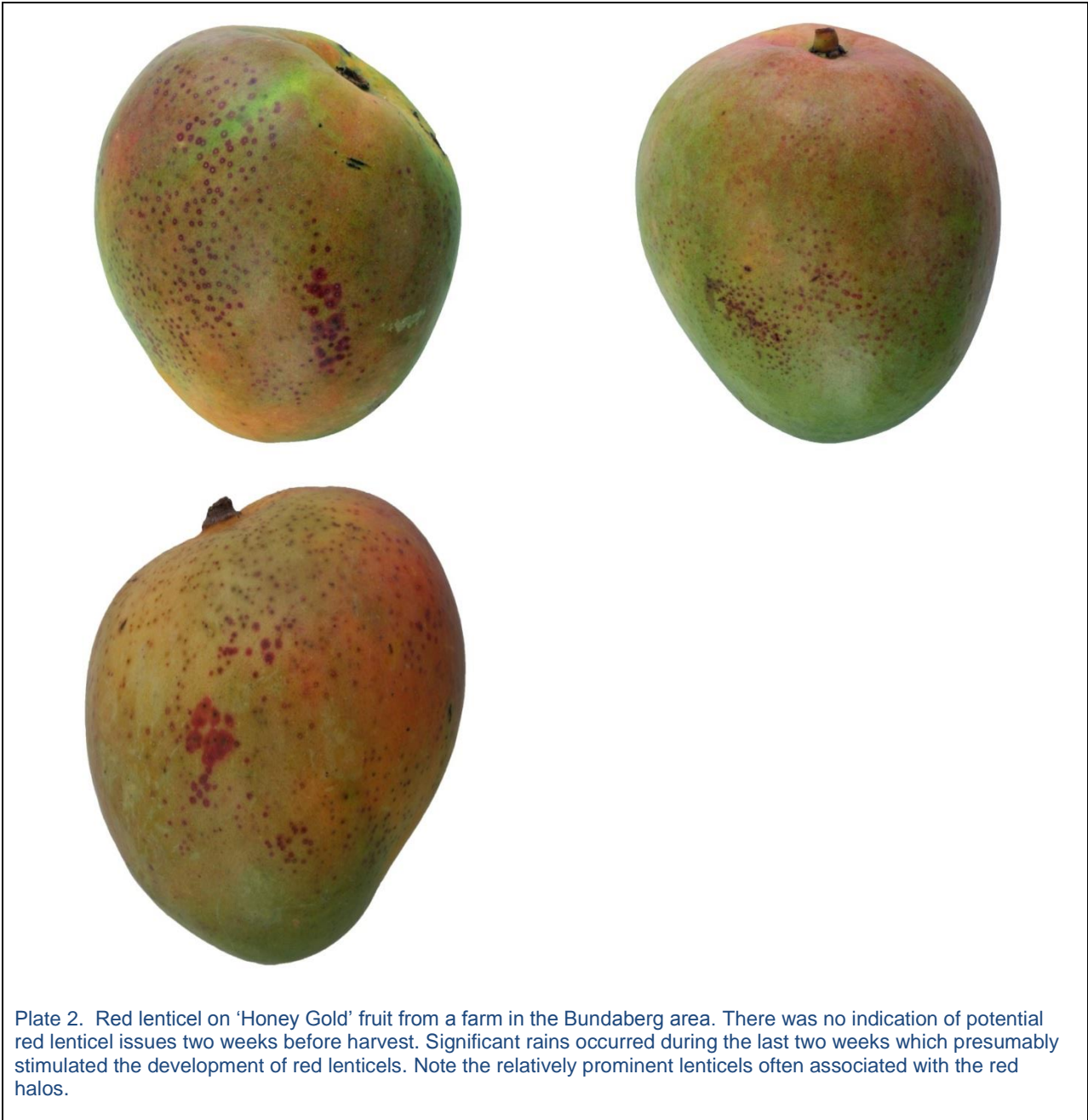
Black lenticel (lenticel spot)



Red lenticel

Plate 1. The main lenticel types observed on 'Honey Gold' mango on farms from the Atherton Tablelands (north Queensland)

Red lenticel was relatively rare on 'Honey Gold' fruit in NQ, but was more prominent in fruit from SQ and nNSW. It was particularly prominent in one farm in the Bundaberg region (Plate 2). A farm visit to the farm by project staff about two weeks before harvest indicated a relatively clean crop with no evidence of red lenticel risk. However, the subsequent two weeks before harvest received considerable rain and most fruit had significant red lenticel at the time of harvest. The symptoms became slightly less obvious as the fruit ripened but still had considerable commercial impact.



Several other issues were identified, but will not be further investigated in this project:

1. **“Bleach lenticel”**. The sun-exposed area of the fruit develops red blush, but overexposure results in bleaching of the exposed area, and in severe cases skin death resulting in dark brown-black damage. The sun bleached area often contains prominent lenticels, presumably because of the increased cell stress associated with higher irradiation. These lenticels are more prone to develop

red lenticel, particularly on the border of the bleached area, and presumably because the sun exposure increases the potential for red pigmentation.

Sun exposure is required for red pigment production which is a positive attribute increasing consumer appeal. Unfortunately, this increases the risk of bleaching. Factors such as row orientation and degree of canopy cover can influence the balance between blush and bleaching/sunburn. These practices are well understood so will not be investigated in this project. However, increasing the ability of the fruit to minimise bleaching from sun exposure without compromising red blush development will be investigated. Photon[®] (<http://www.agricrop.com.au/site/wp-content/uploads/Photon-500SG-Label-29-10-2012-Agricrop.pdf>) is claimed to reduce the impact of environmental stressors. Plans were developed to test photon potential to reduce bleaching and sunburn, but this was not possible in the current season due to whole farm treatment without controls. Trials are planned for the 2015/16 season.

2. **Pepper spot**, also called tear staining (Plate 3). In periods of rain, fruit can sometimes develop small black spots which in some cases develop red halos. The symptoms are more common in trees with dense canopies with dead twigs, flowers and leaves above the fruit. It is thought that consistent rain flushes disease inoculum from the dead material onto the fruit over prolonged periods. This disease inoculum germinates but hypersensitive reactions in the fruit contain the disease to within small black spots. Similar symptoms appear on avocado and lychee and have been associated with the anthracnose organism. The infections are often not associated with lenticel openings, and they can develop red halos particularly on the shoulders of receiving sun exposure.

Control strategies for pepper spot are well-known (orchard hygiene, pruning to maintain an open canopy etc.) and will not be studied in this project.

3. Suspected **chemical burn**. This appears as small (usually about 1 mm diameter), irregular areas of pink-red. There is often a small white spot with irregular margins in the middle of the red discolouration. These small “halos” often occur in the one area of the fruit. This will not be investigated further.

Red skin stain was observed in fruit from nNSW, and has been an ongoing problem from this farm. Symptoms expressed as dark red/purple areas on the fruit on the tree, appearing after considerable rain, and appear to be associated with groves in the shoulder of the fruit where water is likely to drain for the depression around the stem attachment to the fruit (Plate 4). These symptoms often disappeared with 2-3 weeks of fine weather between the rain event and harvest.

Red skin smear was also observed, but mainly after harvest in 2014/15 (Plate 4). This was relatively rare in 2014/15, possibly because of relatively dry conditions in the last few weeks before harvest. However, the grower indicates it is quite common, particularly with rain during the harvest season.

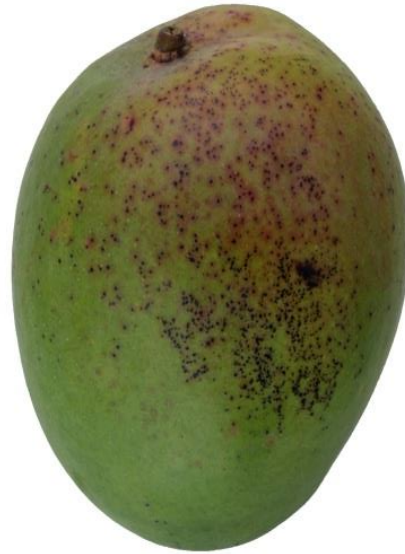


Plate 3. Pepper spot on 'Honey Gold' mango, often with red halos around the infection point. The black areas are generally not associated with the lenticels.



Increasing red blush

This trial was compromised somewhat because of considerable pepper spot due to extensive rain before and during the field treatments.

There were few significant interactions between spray applications before harvest and blue light treatment after harvest, so only the main effects are presented

None of the treatments affected the blush rating at harvest (Table 1). However, at eating soft the sugar treatments and ReTain had significantly more blush than the control, while the bagging treatment had significantly less. All treatments except bagging resulted in lower hue angles (more red) on the skin one day after harvest. It is possible that the water plus Agral was the main factor because hue angle was similar at harvest in all the other spray treatments. There were no significant treatment effects on hue angle at eating soft. There was also no effect of treatment (excluding Ethrel) on the chroma (brightness) one day after harvest or at eating soft.

Ethrel significantly increased the chroma compared with all other treatments, and reduced the hue angle (more red) compared with control. However, this treatment resulted in significant fruit drop by the time the trial was harvested.

These results suggest that the spray applications may result in a greater proportion of the skin with blush on 'Honey Gold' fruit at eating soft. Further work is justified to identify the commercial significance of these effects. Future trials will apply the spray applications earlier during fruit growth to allow adequate time for fruit response. Lower concentrations or less frequent applications of Ethrel should also be investigated.

Fruit for the blue light and the control treatments were not randomly selected, resulting in statistically different levels of blush and hue angle at the start of ripening (Table 2). The lack of random selection was because of significant pepper spot on the fruit and the concern that fruit under blue light would develop considerable disease before a treatment response was obvious. As a result, a blue light response is difficult to identify. However, it appears that the blue light treatment did not enhance blush during ripening since blush rating was significantly greater at harvest in the blue light fruit compared to no blue light, yet the blush was statistically similar to no blue light treatment at ripe. Also, the decrease in hue angle (development of more red colour) was considerably less with blue light treatment than with no blue light treatment. Therefore, there appears to be minimal positive effect of blue light on development of blush during ripening, but further investigation may be required.

Table 1. The response of 'Honey Gold' mango fruit to various field treatments aimed at increasing the area and intensity of red blush at harvest and at eating soft. Treatments were applied from about three weeks before harvest at five day intervals and the fruit harvested about five days after the last treatment. Blush was rated on a 1 (0-10% of the skin with blush) to 6 (90-100% with blush) scale. Chroma and hue angle were measured at 2-3 points on the blush area to represent average blush characteristics. There were no significant interactions between pre-harvest sprays and post-harvest blue light treatments, so the means represent the averages across the blue light treatments. Means in the same column with a different letter are significantly different at P =0.05.

Treatment	Blush rating (1-6)		Chroma		Hue (°)	
	1 d after harvest	At eating soft	1 d after harvest	At eating soft	1 d after harvest	At eating soft
Control	2.3	1.8 ^{bc}	20.9 ^b	52.6	90.1 ^a	67.8
Water+Agral	2.6	2.2 ^{ab}	20.5 ^b	51.2	77.3 ^{bc}	64.2
Bagging	2.3	1.7 ^c	20.1 ^b	53.2	92.3 ^a	67.9
Fructose	2.5	2.4 ^a	20.7 ^b	52.1	76.3 ^{bc}	64.0
Sucrose	2.7	2.4 ^a	20.6 ^b	51.6	75.2 ^{bc}	65.7
Ethrel			45.2 ^a		71.5 ^c	
Retain	2.4	2.3 ^a	20.1 ^b	51.9	81.9 ^b	66.6

Table 2. The response of 'Honey Gold' mango fruit to LED blue light treatment during the whole ripening period at 20°C. Blush was rated on a 1 (0-10% of the skin with blush) to 6 (90-100% with blush) scale. Hue angle was measured at 2-3 points in the blush area to represent average blush characteristics. There were no significant interactions between pre-harvest sprays and post-harvest blue light treatments, so the means represent the average across the field treatments. Means in the same column with a different letter are significantly different at P =0.05.

Treatment	Blush rating (1-6)		Hue		
	1 d after harvest	At eating soft	1 d after harvest	At eating soft	Change in Hue
No Blue Light	2.3 ^b	2.0	85.7 ^a	66.6	-19.2 ^b
Blue Light	2.8 ^a	2.3	73.9 ^b	64.8	-9.1 ^a

Reducing rain contact with fruit

Fruit bagging increased the number of white lenticels cm⁻² (Table 3). Bagging also reduced the number of black and red lenticels compared with all other treatments, except TFC for black lenticels and Raingard for red lenticels. Raingard also resulted in significantly lower number of red lenticels cm⁻² compared with the control. Bagging increased the percentage of white lenticels and reduced the percentage of black and red lenticels, and Raingard and TFC reduced the percentage of red lenticels compared with the control. There were no significant treatment effects on total lenticel severity ratings or the severity of red or black lenticels at eating soft. This suggests that the treatments had no commercial impact on red lenticel, although the lenticel counts suggested the potential for positive treatment responses.

Table 3. The response of 'Honey Gold' mango fruit to treatments aimed at reducing the impact of rain on red lenticel. Fruit were sprayed with various chemicals four times at weekly intervals. The number of white, black or red lenticels cm⁻², and the percentage of the lenticel types relative to the total lenticel number was estimated about four times from harvest through to ripe, and the average presented. Means in the same column with a different letter are significantly different at P =0.05.

Treatment	No. of lenticels/cm ²			% of total lenticels		
	White lenticels	Black lenticels	Red lenticels	White lenticels	Black lenticels	Red lenticels
Control	2.9 ^b	2.7 ^{ab}	1.54 ^a	43.4 ^c	36.0 ^a	20.6 ^a
Agral	4.1 ^b	2.6 ^{ab}	1.12 ^{ab}	51.1 ^{bc}	33.7 ^a	15.1 ^{abc}
Raynox	3.7 ^b	2.9 ^a	1.25 ^{ab}	44.1 ^c	37.0 ^a	18.9 ^{ab}
Raingard	3.8 ^b	2.3 ^{ab}	0.85 ^{bc}	54.0 ^b	33.0 ^a	12.9 ^c
TFC	4.1 ^b	2.0 ^{bc}	1.09 ^b	56.1 ^b	29.2 ^a	14.8 ^{bc}
Bagging	7.4 ^a	1.5 ^c	0.51 ^c	75.0 ^a	18.5 ^b	6.5 ^d

Bagging resulted in darker, and less red hued blush three days after harvest and at eating soft, although the effects were very small (Table 4). However, there were no significant treatment effects on the percentage of fruit area with blush.

Table 4. Effect of various spray treatments and fruit bagging aimed at reducing the effects of water on red lenticel on the L value (darkness), chroma (brightness) and hue (lower numbers indicate more red) of the blush area on 'Honey Gold' mango fruit. Means in the same column with a different letter are significantly different at P =0.05.

Treatment	L Value			Chroma			Hue (°)		
	Day 3	Eating soft	Change	Day 3	Eating soft	Change	Day 3	Eating soft	Change
Control	57.1 ^a	59.7 ^{bcd}	2.6 ^{bc}	30.0	47.0 ^a	17.5 ^{bc}	71.9 ^{bc}	56.3 ^b	-15.8 ^a
Agral	55.1 ^b	58.3 ^d	3.5 ^{ab}	28.4	47.0 ^a	19.9 ^{ab}	68.7 ^c	53.8 ^{bc}	-15.3 ^a
Raynox	56.5 ^{ab}	59.1 ^{cd}	2.8 ^{bc}	28.5	45.1 ^{bc}	17.7 ^{abc}	69.4 ^{bc}	53.3 ^c	-17.0 ^a
Raingard	58.1 ^a	60.2 ^{bc}	2.1 ^c	28.6	44.2 ^c	15.6 ^c	71.0 ^{bc}	55.8 ^{bc}	-15.1 ^a
TFC	58.0 ^a	60.6 ^b	2.7 ^{bc}	29.5	46.2 ^{ab}	16.8 ^c	75.6 ^b	56.4 ^b	-19.2 ^a
Bagging	57.7 ^a	62.4 ^a	4.9 ^a	27.7	47.5 ^a	20.2 ^a	84.2 ^a	59.6 ^a	-25.0 ^b

There was no effect of treatment on days to eating soft (data not presented).

Significant rains occurred following the second spray application, which is often associated with increased risk of red lenticel. However the subsequent 2-3 weeks before harvest were relatively dry. This likely reduced red lenticel expression and the potential for positive treatment responses.

Research progress with this defect is dependent on suitable climatic conditions during the trial. Consideration for future trials will include overhead micro-sprinklers for treatment trees to increase the potential for red lenticel. Raingard and bagging will likely be investigated in more detail next season. Additional consideration will be given to treatments that manipulate stress responses based on the hypothesis that water entry into the lenticel cavity and the cells surrounding the lenticel results in a stress response and anthocyanin production.

Ethylene effects

There were few significant interactions between ethylene treatment and commercial practice, so only the main effects are presented.

Fruit not treated with ethylene ripened in about 15 days, while fruit from all other ethylene treatments ripened in 10-11 days, and with no significant difference between the concentrations. Ethylene treatment generally resulted in more severe red lenticel compared with no ethylene treatment (Table 5), but the effects were only small at 20-100 ppm, which is less than the commercially recommended 10 ppm concentration used in trickle ethylene ripening systems. Plate 5 illustrates the symptoms observed, especially with 500 ppm.

Ethylene treatment reduced the average brightness and increased the red colour (lower hue angle) of the blush, but these effects were small (Table 5). There were no significant ethylene treatment effects on the area of the fruit with blush, blotchiness or smudging of the blush area, or total lenticel damage severity.

These results indicate the potential for ethylene to increase red pigment production, although the effects are likely to be small under good ripening practices. Simulated commercial picking and packing increased the darkness (L value) brightness (chroma) and red colour (reduced hue angle) on the blush of the ripe fruit (Table 6) but these effects were small.

Table 5. Effect of three days ethylene treatment at several concentrations at 20°C on the severity of red lenticel and the chroma and hue angle of the blushed area on 'Honey Gold' mango fruit. The ratings were done at the eating soft stage and the means are the average for both with and without commercial treatment. Means in the same column with a different letter are significantly different at P =0.05.

Ethylene concentration	Red lenticel score (0-5)	Chroma	Hue
0 ppm	1.6 ^c	51.1 ^a	67.3 ^a
20 ppm	2.1 ^{ab}	48.5 ^b	63.7 ^b
100 ppm	1.9 ^{bc}	47.2 ^b	60.7 ^c
500 ppm	2.4 ^a	46.8 ^b	60.6 ^c

Table 6. The effect of commercial postharvest treatments (Mango Wash, brushing and fungicide treatment) and no commercial postharvest treatment on the L value (darkness), chroma (brightness) and hue angle (lower values are more red) of the blushed area on ripe 'Honey Gold' mango fruit. The means are averaged across the ethylene concentrations. Means in the same column with a different letter are significantly different at P =0.05.


Commercial postharvest practices	L* value	Chroma	Hue
Yes	62.6 ^a	49.3 ^a	64.0 ^a
No	60.9 ^b	47.4 ^b	62.1 ^b



Plate 5. Red pigment defects noted on 'Honey Gold' fruit in the ethylene trial. The red colouration was often associated with lenticels but not in all cases.

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Reducing or masking red lenticel disorder in ‘Honey Gold’ mango

Improving consumer appeal of ‘Honey Gold’ mango
(MG13016)

Peter Hofman, Daryl Joyce, Andrew Macnish, Pip Bryant,
Lawrence Smith, Gavin Scurr, Liz Dann

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This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

'Honey Gold' mangoes grown in cooler climate production areas are susceptible to red lenticel disorder, characterised by red discolouration surrounding the lenticels. The disorder is often associated with heavy rainfall in the weeks leading up to harvest. Red lenticel disorder is thought to occur due to stress induced production of anthocyanin, the same pigment associated with blush. Possible methods of reducing the impact of red lenticel disorder include reducing anthocyanin synthesis, or alternatively enhancing the blush response to mask red lenticel symptoms.

Previous trials have shown some reductions in red lenticel disorder through pre-harvest fruit bagging. The present trial aimed to explore additional bagging materials, including two varieties of spun-bonded plastics; frost cloth and Tyvek®. The bagging treatments that blocked the most light, paper and Tyvek®, had the most substantial impact in reducing sun damage, blush and red lenticel disorder.

Exposure to blue LED lights during the postharvest period has been shown to enhance the blush response. In the present trial an intermittent exposure in 48 h cycles was compared with constant blue light. The LED lights used in the present trial emitted less light than those used the previous season, and did not induce a strong blush response. A mild blush response was observed at week 3-4 in 12°C stored fruit, following the same trend as was observed in previous research.

A recently developed elicitor derived from sorghum bio-refinery waste, CDS (condensed distillers solubles) was tested, after a blush response in mango was observed in an unrelated trial. CDS resulted in a strong blush response, but the blush was patchy and uneven. The treatment also induced brown patchy skin discolouration, extreme dark lenticel spotting and greater severity of red lenticel disorder. Lower concentrations of CDS would be recommended for future experimentation to avoid damage to the fruit.

Methyl jasmonate (MeJA) did not successfully induce blush in previous trials on 'Honey Gold' mangoes, but was anecdotally observed to result in more uniform, visually appealing trays of fruit. MeJA vapour treatments were retested in the present trial, and did not show any significant effects on blush, red lenticel disorder, or skin colour homogeneity.

Pre-harvest bagging to block light from the fruit was the most reliable technique identified to reduce red lenticel damage. The use of bagging as a commercial option would need to take into account the costs, time commitment and the associated reduction in blush on the fruit.

Introduction

Red lenticel disorder in 'Honey Gold' mango is observed in cooler climate production areas, particularly south of Rockhampton, and is characterised by the development of red halos around the lenticels. The development of the disorder on 'Honey Gold' mango has been anecdotally associated with high rainfall in the 2-4 weeks prior to harvest. It is hypothesised that the rain, possibly in conjunction with other factors, induces a stress response in the lenticels, triggering the production of anthocyanins. The visual impact of red lenticel could be lessened by either reducing the development of red pigment around the lenticels, or increasing the overall red colouration of the fruit to mask the red lenticels.

In previous seasons exploratory trials have examined options for either reducing or enhancing the blush response. Pre-harvest bagging of fruit using paper bags showed some promise in reducing the red lenticel response. This reduction in red colour development could have occurred through protection against rain or reduced exposure to light, as anthocyanin development is typically promoted by light exposure (Zoratti et al., 2014). The present trial aimed to explore more options in materials for pre-harvest bagging, comparing paper, LDPE plastic and spun-bonded polyethylene (frost cloth) and Tyvek®.

Postharvest exposure to blue light has shown promise in enhancing mango blush (Cao et al., 2016; Poudel et al., In press), which could potentially mask the red lenticel symptoms. The present trial aimed to explore different regimes of applying postharvest blue light, comparing continuous and intermittent exposure.

Methyl jasmonate (MeJA) was tested last season for effects on blush development, and, while blush was not enhanced, the treatment appeared to result in more uniform, visually appealing trays of fruit. Similar effects have been observed on tomatoes, with greater homogeneity of colour and firmness shown in MeJA treated fruit (Baltazar et al., 2007). The effect has also been observed in 'Manila' mangoes, where colour change from green to yellow occurred more quickly and uniformly after treatment with MeJA (Herrera et al., 2004). MeJA was retested this season to observe effects on homogeneity and ripening on the 'Honey Gold' variety.

Additionally, a recently developed elicitor derived from sorghum biorefinery waste, CDS (condensed distillers solubles) (Navarro et al., 2016), showed enhancement of red colour development in mango while being used in an unrelated trial. This elicitor was tested for effects on red lenticel and blush.

The research aimed to explore techniques by which blush responses in 'Honey Gold' mangoes could be inhibited or enhanced. Inhibiting the blush response could potentially reduce the development of red lenticel disorder, while enhancing the blush could mask red lenticels. Techniques developed to enhance blush may also provide benefits in increasing fruit marketability, with consumers tending to prefer fruit with blush (Hofman, 1997).

Materials and Methods

Fruit

'Honey Gold' mangoes were harvested at the mature hard green stage from a commercial orchard near Yelgun in northern New South Wales (nNSW), Australia (28°29'06"S 153°30'29"E). The fruit were harvested from 8th to 15th February, 2017. The fruit dry matter was measured at 17.9% by the grower on 10th February. Fruit were harvested by hand using secateurs, with methylated spirit spray used between trees to prevent disease transfer. After harvest, the fruit were destemmed, washed in mango wash for 1 min, and processed through the packing line, with washing over rollers using Sunlight soap, and a fungicide spray of Scholar®. The fruit were transferred by car to Maroochy Research Facility (MRF), Nambour, Southeast Queensland (SEQ), and were stored overnight at 16°C prior to assessment the next day.

Weather conditions

A weather station was installed to collect weather data at the orchard site. From the time of bagging (10th January, 2017) until harvest, the weather conditions recorded on site averaged a relative humidity (RH) of 80%, with average daily range of 61-94% RH. Average daily maximum temperature was 31°C and minimum 21°C, and average wind speed was 2 km/h, with an average daily maximum of 7 km/h and overall maximum of up to 11 km/h (a light breeze). These conditions were typical of the area, being close to recorded averages at nearby stations. Solar exposure was also typical in January and February, with monthly averages close to the historical mean values. BOM rainfall records from the nearest station (Mullumbimby (Fairview Farm)), located at 28.55°S, 153.49°E, indicate an average amount of rainfall over January, and a much drier than average February (58 mm over the month, with a mean rainfall of 234 mm).

Fruit assessment

Fruit were assessed for skin colour, firmness, blush and red lenticel disorder. At the initial assessment, each fruit was marked with three numbered locations for repeated background skin colour readings, not within the blush area or in blemished areas. Fruit were assessed for skin colour using a Minolta colour meter (CIELab scale), with hue angle and chroma calculated according to McGuire (1992). Minolta colour readings were taken at the 3 marked background sites and at the site of most intense blush colour.

Hand firmness (fruit softness) (0-4) was assessed according to the scale described in Holmes et al. (2010), where 0 = hard to 4 = soft. Skin colour was assessed as the % surface area (%SA) of the whole

fruit allocated to blush, yellow and green. These values were then used to determine skin colour and blush scores (1-6) as adapted from Holmes et al. (2010).

Skin colour rating scale		Blush rating scale	
1	0-10% yellow	1	0-10% blush
2	11-30% yellow	2	11-30% blush
3	31-50% yellow	3	31-50% blush
4	51-70% yellow	4	51-70% blush
5	71-90% yellow	5	71-90% blush
6	91-100% yellow	6	91-100% blush

Fruit were rated for the extent of red or dark lenticel disorder according to the percentage of fruit surface area affected (Holmes et al., 2010).

Lenticel rating scale

0	Nil
1	Less than 5% SA
2	5-10%
3	10-25%
4	25-50%
5	More than 50%

An additional assessment was undertaken when fruit were at or near eating ripe, typically at a firmness rating of 4 and skin colour rating of 6. Fruit were reassessed for firmness, skin colour and red lenticel disorder, and Minolta colour readings were taken at the 3 marked sites, and at the site of most intense blush colour.

Pre-harvest bagging trial

Fruit were bagged using a variety of materials (Table 1), with each treatment applied to one fruit on each of 24 trees. Bags were cut open at both ends, and were sealed along the sides. A heat sealer was used to seal the spun-bonded material into tubes. The bags were secured on the stem above the fruit using a cable tie and remained open bottomed to allow air circulation. The fruit selected for bagging were as uniform as possible in size, position in tree and degree of maturity. Bagging treatments were randomly allocated to the east or west side of the canopy, in a balanced design, with a control fruit for each orientation (east or west) on each tree. Treatments were randomly allocated to the fruit selected for treatment. Bags were placed on the fruit on 10th January, 2017, approximately 6 weeks prior to the anticipated harvest date. Early fruit maturity resulted in an earlier than expected harvest on 8th February, 2017, resulting in a treatment period of 4 weeks. Fruit were processed through the packing line after harvest and were transferred to MRF, Nambour. An initial assessment was carried out the next day. Fruit were treated with 10 ppm ethylene at 20°C for 3 days, ripened at 20°C, and reassessed at eating ripe.

Table 1: Bagging treatments applied 4 weeks prior to harvest on 'Honey Gold' mangoes grown in Yelgun, NNSW.

Treatment	Details
Control (East)	Fruit on the east side of the tree, with no bagging.
Control (West)	Fruit on the west side of the tree with no bagging.
Paper bag	Fruit were bagged in brown 240 x 330 mm paper bags of approx. 36 gsm weight.
Clear polyethylene	Fruit were bagged in clear 230 x 380 mm 35µm LDPE bags.
Frost protection	Fruit were bagged in a single layer of 'Groshield™' 30 g/m ² white spun-bonded polypropylene, permeable to water.
Tyvek®	Fruit were bagged in a single layer of 75 gsm Tyvek® spun-bonded olefin, a water barrier (hydrophobic) with vapour permeability.

The light properties of the various bagging materials were measured using a Rainbow Light Microspectrometer (model HSM-01). Measurements were made in full sun between 11:15am-12:10pm.

Additional readings of light properties were made with Solarmeter digital radiometers (Solatech Inc, USA) for red, blue and UV light (Blue light model 9.4 with spectral range 422-499 nm; Red light model 9.6 with spectral range 585-741 nm; UVC model 8.0 with spectral range 246-262 nm). These measurements were taken in full sun on a clear day at 12:00-12:30pm.

Dendrometers (Model FI-M Fruit Growth Sensor, Bio Instruments S.R.I., Moldova) were used to monitor fruit diameter over a 7 week period (10th January to 1st March, 2017) on 2 replicate nubbins (seedless fruit) growing on 2 neighbouring trees used in the bagging trial.

Postharvest light exposure trial

Treatments of blue and white LED light exposure during postharvest storage were trialled at two storage temperatures. For each of the 8 postharvest light treatments (Table 2), one fruit was treated from each of 15 trees. Fruit were harvested by hand on 15th February, 2017, and were selected for uniformity in size, position in tree and degree of maturity. After harvest, fruit were processed through the farm packing line, and then transferred to MRF, Nambour. Fruit were stored overnight at 16°C, were assessed the next day, and were then placed into light treatment.

Light treatments were applied to 3 replicate trays for each treatment, with 5 fruit per replicate. Fruit were randomly allocated to treatments in replicate groups based on tree number (fruit from trees 1-5 formed replicate 1, trees 6-10 formed replicate 2 and trees 11-15 formed replicate 3). At the initial assessment fruit were marked for repeated colour readings. All 3 marked colour reading sites were located on one side of the fruit, and these were orientated upwards to allow light exposure. LED strip lights (each 115 cm in length, with 69 LED lights per tray) were attached to mango trays, and these were inverted over the fruit tray at 300 mm height. Each individual treatment tray was sectioned off from others using black cloth. Treatment areas were randomly arranged within each cool room in grouped replicate blocks. Temperatures within trays were recorded using HOBO data loggers at 15 minute intervals throughout the treatment period. Fruit were assessed and photographed weekly until at eating ripe.

Table 2: Postharvest light treatments applied to 'Honey Gold' mangoes grown in Yelgun, NNSW.

Treatment	Details
Continuous control 12°C	Fruit were stored at 12°C without exposure to light until at eating ripe.
Continuous control 22°C	Fruit were stored at 22°C without exposure to light until at eating ripe.
Continuous white light 12°C	Fruit were stored at 12°C under white LED strip lights until at eating ripe.
Continuous white light 22°C	Fruit were stored at 22°C under white LED strip light until at eating ripe.
Continuous blue light 12°C	Fruit were stored at 12°C under blue LED strip light until at eating ripe.
Continuous blue light 22°C	Fruit were stored at 22°C under blue LED strip light until at eating ripe.
Intermittent blue light 12°C	Fruit were stored at 12°C, with exposure to blue LED strip light for 48 h periods, alternated with 48 h periods of darkness until at eating ripe.
Intermittent blue light 22°C	Fruit were stored at 22°C, with exposure to blue LED strip light for 48 h periods, alternated with 48 h periods of darkness until at eating ripe.

The light properties of the LED light treatments were measured using a Rainbow Light Micro-spectrometer (model HSM-01), and Solarmeter digital radiometers (Solatech Inc, USA).

CDS trial

A recently developed defence elicitor formulation, CDS (condensed distillers solubles) was tested for effects on blush. CDS was obtained from Dalby Bio-Refinery Ltd, and was applied as a postharvest dip at varying concentrations, and with and without surfactant (Table 3). Each of the 6 treatments was applied to 1 fruit from each of 25 trees. Fruit were harvested by hand on 10th February, 2017, processed through the farm packing line and transferred to MRF. Fruit were stored overnight at 16°C, and were assessed the next morning. Fruit were randomly allocated to treatment groups, and dip treatments were applied.

After treatment, the fruit were air-dried, treated with ethylene (10 ppm at 20°C for 3 days) and ripened at 20°C. Fruit were reassessed at eating ripe.

Table 3: CDS (condensed distiller solubles) treatments applied to 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Details
Untreated control	No treatment applied.
Water	Fruit were treated with a postharvest dip in water for 1 min at RT.
Water with surfactant	Fruit were treated with a postharvest dip in water with Union surfactant (at 5 mL per 10 L) for 1 min at RT.
25% CDS	Fruit were treated with 25% CDS as a 1 min dip at RT.
50% CDS	Fruit were treated with 50% CDS as a 1 min dip at RT.
25% CDS with surfactant	Fruit were treated with 25% CDS with Tween 20 surfactant (at 5 mL per 10 L) as a 1 min dip at RT.

MeJA trial

MeJA was tested for effects on ripening and fruit colour. Each MeJA treatment was applied both with and without exposure to ethylene (Table 4). One fruit from each of 24 trees was allocated to each of the 8 treatment groups (MeJA x ethylene). Within each treatment group, fruit were divided into 3 replicates grouped by tree number (fruit from trees 1-8 formed replicate 1, trees 9-16 formed replicate 2 and trees 17-24 formed replicate 3). The fruit selected were as uniform as possible in size, position in tree and degree of maturity, and were randomly allocated into treatment groups.

Fruit were harvested on 13th February, 2017, were processed through the packing line, transferred to MRF and assessed. Vapour treatments were applied by pipetting MeJA onto filter paper within a water-sealed plastic container, with each replicate treatment applied in a separate container. A measurement of CO₂ in each container was taken using Kitagawa gas detector tubes (Komyo Rikagaku Kogyo, Kanagawa, Japan) at the end of the treatment period to confirm an air-tight seal was maintained. The treatment groups with ethylene were treated with 10 ppm ethylene at 20°C for 3 days. All fruit were ripened at 20°C, and were reassessed at eating ripe.

Table 4: MeJA treatments applied to 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Details	Ethylene
Untreated control (+)	No treatment applied.	+ ethylene
Untreated control (-)	No treatment applied.	- ethylene
Vapour control (+)	Fruit stored in a sealed container for 24 h duration at 20°C.	+ ethylene
Vapour control (-)	Fruit stored in a sealed container for 24 h duration at 20°C.	- ethylene
0.1 mM MeJA (+)	MeJA applied as a vapour at 0.1 mM (22 ppm) within a sealed container for 24 h duration at 20°C.	+ ethylene
0.1 mM MeJA (-)	MeJA applied as a vapour at 0.1 mM (22 ppm) within a sealed container for 24 h duration at 20°C.	- ethylene
0.3 mM MeJA (+)	MeJA applied as a vapour at 0.3 mM (66 ppm) within a sealed container for 24 h duration at 20°C.	+ ethylene
0.3 mM MeJA (-)	MeJA applied as a vapour at 0.3 mM (66 ppm) within a sealed container for 24 h duration at 20°C.	- ethylene

Analysis

Statistical analyses were performed using Genstat® 14 for Windows™ (VSN International Ltd., UK). Data were analysed using the 'General Analysis of Variance' model, with trees as a blocking factor, and

individual fruit as experimental units. The least significant difference (LSD) procedure at $P=0.05$ was used to test for differences between treatment means.

Results and discussion

Pre-harvest bagging trial

Dendrometer measurements

Measurements of fruit diameter on nubbins showed the diurnal fluctuation in diameter and gradual growth of the fruit (Figure 1, Figure 2). The 2 replicate nubbins monitored showed different patterns of diurnal fluctuation, with nubbin 1 showing more pronounced fluctuation in diameter. In both nubbins, the period of most rapid growth tended to occur from around 6am to 8am. The decline in diameter in nubbin 1 was typically most rapid in the evening, from around 5pm until 8-10pm. The fruit were located on 2 neighbouring trees. Differing water supply to the fruit from the trees may have contributed to these different diurnal patterns of growth.

Figure 1: Fruit diameter monitored by dendrometer over a two week period on 'Honey Gold' nubbins grown at Yelgun, northern NSW.

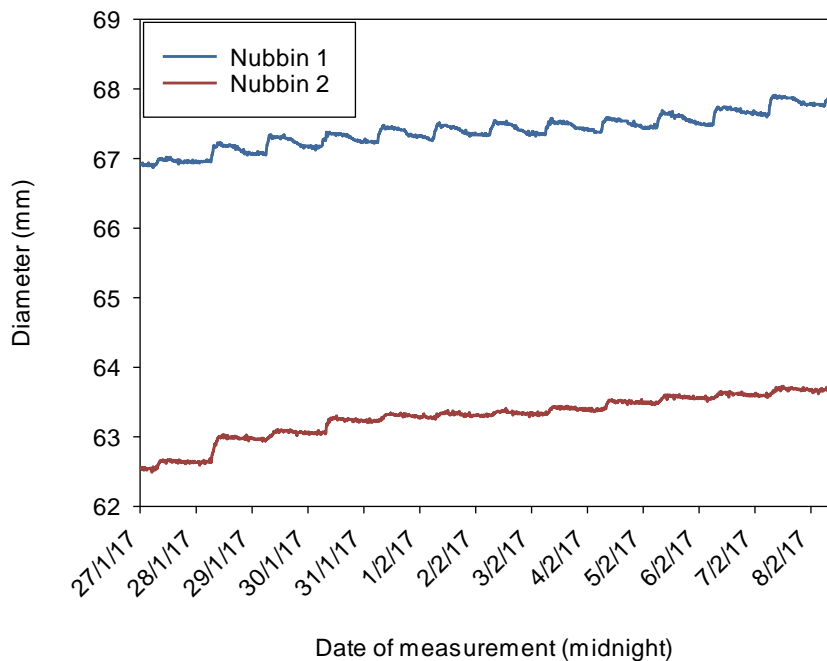
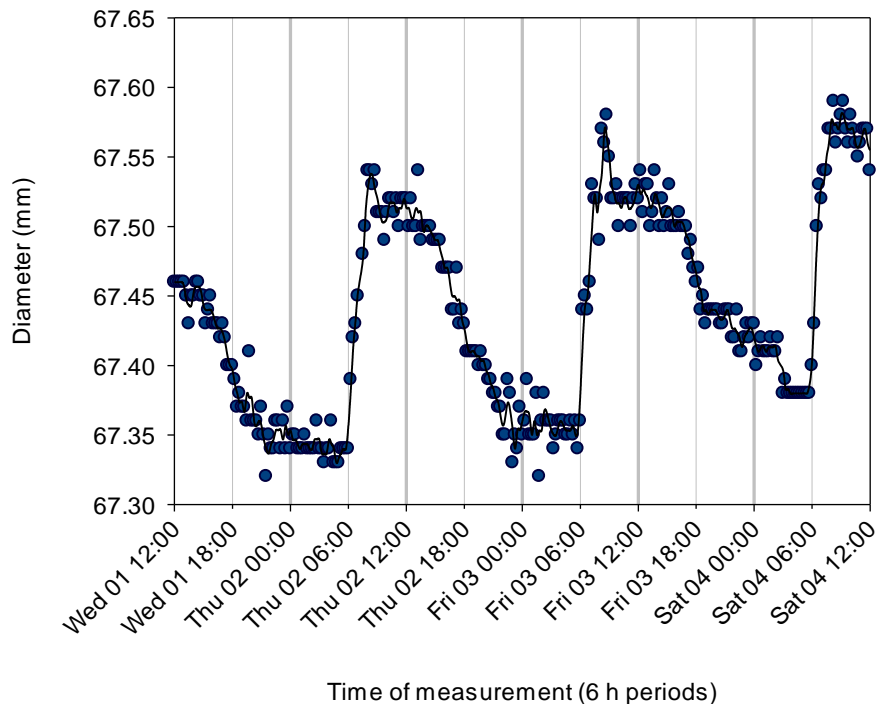


Figure 2: Diurnal pattern in fruit diameter monitored by dendrometer over a 3 day period on a 'Honey Gold' nubbin ('Nubbin 1' from figure above) grown at Yelgun, northern NSW (symbols show actual 15 minute interval readings, and line 30 min averaged readings).



Light measurements

The light levels under various bagging materials were measured on a clear day near midday (Figure 3). The clear plastic bag caused minimal changes to the light spectrum reaching the fruit surface. Frost cloth slightly reduced the light reaching the fruit, very slightly reducing the light intensity. The effect of frost cloth in blocking light was more evident in single point light measurements (Table 5), which were around 50-70% of the values shown in full sun. Paper and Tyvek® bags substantially reduced the light reaching the fruit, with Tyvek® tending to block more light. However, in the blue light wavelength range (422-499 nm) paper bags blocked slightly more light than Tyvek®. None of the bagging treatments reduced the light intensity as strongly as the shade of the mango canopy.

Figure 3: Light intensity spectra under various bagging materials, measured near midday in full sun at Yelgun, NNSW.

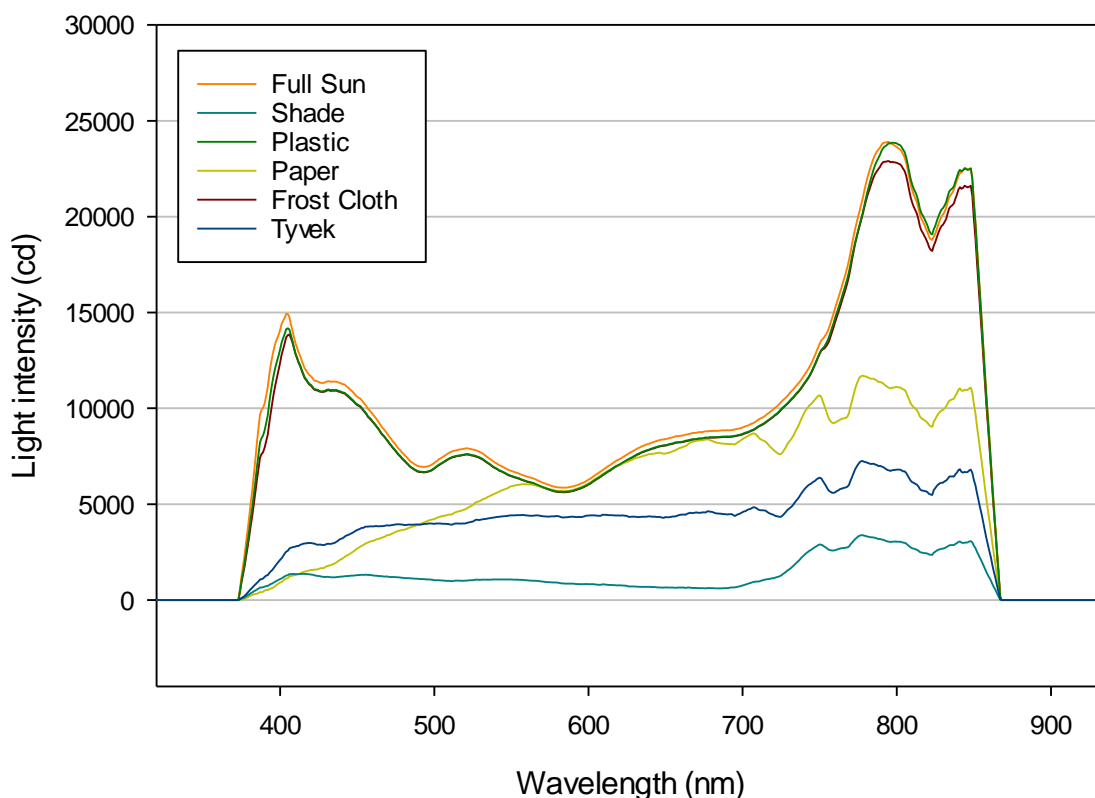


Table 5: Single point light readings under various bagging materials measured near midday in full sun at Yelgun, NNSW.

Treatment	Red light (mW/cm ²) (585-741 nm)	Blue light (mW/cm ²) (422-499 nm)	UVC light (μW/cm ²) (246-262 nm)
Ambient (full sun)	19.6	11.2	8.3
Clear plastic	17.7	10.6	6.3
Paper	4.6	1.3	0.0
Frost cloth	12.5	7.8	4.0
Tyvek®	2.6	1.5	0.0

Fruit responses to bagging

Bagging in paper or Tyvek® bags substantially reduced the amount of sun damage at harvest (Table 6). Sun damage was typically observed as bleached or faded skin colour on the shoulder of the fruit. This type of damage generally became less obvious as the fruit ripened. More extreme sun damage, characterised by dark sunken lesions, was observed in some fruit treated using clear plastic bags. Sun damage was significantly increased by bagging in clear plastic bags, probably due to the bags creating a hot microclimate around the fruit. Sun damage was greater on west facing fruit, exposed to the afternoon sun in the hottest part of the day, as compared to east-facing fruit. The bagging treatments that blocked the most light, paper and Tyvek®, had the most beneficial effect in reducing sun damage.

Dark lenticel damage observed at harvest was reduced by frost cloth and Tyvek® bags. Water stress and high humidity around the fruit can exacerbate dark lenticel spotting (Holmes et al., 2010). Protection from the elements, combined with the ability of these bags to allow ventilation around the fruit may have been of benefit in reducing the disorder. Dark lenticel spotting was also observed more in west facing than east facing fruit, possibly due to the fruit being stressed by exposure to the hot afternoon sun. These effects were temporary, as when fruit reached eating ripe, no treatment or orientation effects on dark lenticel spotting were detected (data not shown).

Red lenticel damage at harvest was substantially reduced by paper and Tyvek® bags, the bagging treatments that blocked the most light. It is likely that reduced light reaching the fruit limited the synthesis of the red pigment anthocyanin, which is typically promoted by light exposure (Zoratti et al., 2014). East facing fruit showed slightly more severe red lenticel disorder than west facing fruit. While total light exposure is likely to be similar in east and west facing fruit, west facing fruit would typically be exposed to higher temperatures in the afternoon sun. This exposure to heat may have countered the effect of light exposure on anthocyanins, as high temperatures can inhibit the production or promote the degradation of anthocyanin in developing fruit (Haselgrove et al., 2000).

Table 6: Effect of bagging treatments and fruit orientation on sun damage and lenticel disorders at harvest in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Sun damage (%SA) at harvest	Dark lenticel score (0-5) at harvest	Red lenticel score (0-5) at harvest
Unbagged control	11.6 ^b	1.8 ^{ab}	1.4 ^a
Paper bag	2.5 ^c	1.4 ^{bc}	0.3 ^b
Clear plastic bag	17.0 ^a	2.2 ^a	1.5 ^a
Frost cloth	9.1 ^b	0.9 ^c	1.3 ^a
Tyvek®	0.5 ^c	1.0 ^c	0.3 ^b
LSD	4.08	0.61	0.51
East	6.9 ^b	1.2 ^b	1.2 ^a
West	10.6 ^a	1.9 ^a	0.8 ^b
LSD	2.49	0.37	0.31

Data analysed by two factor ANOVA of bagging treatment and orientation (east/west) with fruit as the experimental unit (n=24-48). Means with the same letter within each column and section are not significantly different (at p<0.05) as tested by LSD.

Blush development on the fruit was strongly reduced by paper and Tyvek® bagging treatments (Table 7). At harvest, the blush area on east facing fruit was reduced by all bagging treatments, with paper and Tyvek® bags showing the strongest reduction. West facing fruit showed less blush development than east-facing fruit, probably due to the balance between light stimulating and heat inhibiting anthocyanin production. The response to bagging treatments was shown more weakly in west-facing fruit, with paper, frost cloth and Tyvek® significantly reducing blush. The same trends are also reflected in measurements of blush hue after harvest. The higher hue values in bagged fruit indicate less red-purple colour development in the blush. Similar trends persisted when the fruit reached eating ripe, with west-facing fruit showing less blush area than east-facing fruit. Paper and Tyvek® bags reduced blush most strongly at eating ripe, while frost cloth reduced blush on the west, but not east facing fruit. Fruit covered with bags that blocked the most light developed the least blush, with paper and Tyvek® bags substantially reducing blush area and colour development.

Table 7: Bagging treatment and fruit orientation interacting effects on blush development in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Blush (%SA) at harvest		Blush hue (°) at harvest		Blush (%SA) at eating ripe	
	East	West	East	West	East	West
Unbagged control	31.7 ^a	12.8 ^c	71.2 ^f	81.7 ^{de}	41.7 ^a	26.8 ^b
Paper bag	6.7 ^{ef}	1.8 ^f	91.3 ^{bc}	103.7 ^a	10.5 ^{cd}	1.8 ^{de}
Clear plastic bag	22.9 ^b	13.1 ^{cd}	84.0 ^{cde}	78.6 ^e	35.0 ^a	23.4 ^b
Frost cloth	25.4 ^b	6.9 ^{def}	79.2 ^e	88.7 ^{bcd}	38.8 ^a	12.4 ^c
Tyvek®	10.4 ^{cde}	2.0 ^f	93.6 ^b	102.8 ^a	23.1 ^b	1.3 ^e
LSD	5.94	5.94	7.90	7.90	8.54	8.54

Data analysed by two factor ANOVA of bagging treatment and orientation (east/west) with fruit as the experimental unit (n=24). Means with the same letter within each pair of columns are not significantly different (at p<0.05) as tested by LSD.

The effects of bagging on blush development and red lenticel persisted when fruit reached eating ripe (Table 8). Blush hue was higher in paper, frost cloth and Tyvek® bagged fruit, indicating less red-purple colour development compared with the control. At eating ripe, blush hue was lower in east than west facing fruit, indicating more red-purple colour development in east facing fruit. Similarly, red lenticel disorder was more pronounced in east facing fruit. Red lenticel disorder was significantly reduced by all bagging treatments, with paper and Tyvek® bagged fruit showing the lowest levels of the disorder.

Table 8: Bagging treatment and orientation effects on blush and red lenticel disorder in Honey Gold fruit grown at Yelgun, NNSW, at eating ripe.

Treatment	Blush hue (°) at eating ripe	Red lenticel score (0-5) at eating ripe
Unbagged control	57.5 ^c	2.7 ^a
Paper bag	69.7 ^a	0.4 ^c
Clear plastic bag	59.3 ^{bc}	2.0 ^b
Frost cloth	61.5 ^b	1.9 ^b
Tyvek®	67.3 ^a	0.5 ^c
LSD	2.87	0.53
East	58.9 ^b	2.0 ^a
West	65.3 ^a	1.4 ^b
LSD	1.75	0.32

Data analysed by two factor ANOVA of bagging treatment and orientation (east/west) with fruit as the experimental unit (n=24-48). Means with the same letter within each column and section are not significantly different (at p<0.05) as tested by LSD.

The clear plastic bag treatment resulted in fruit that ripened more rapidly, reaching eating ripe around a day earlier than other fruit (Table 9). This may have been due to greater exposure to heat and other associated stresses during the final stages of fruit development on the tree.

Table 9: Effects of bagging treatments on the days taken to reach eating ripe in 'Honey Gold' mangoes grown in Yelgun, NNSW.

Treatment	Days to reach at eating ripe
Unbagged control	9.2 ^a
Paper bag	9.0 ^a
Clear plastic bag	7.8 ^b
Frost cloth	9.4 ^a
Tyvek®	9.5 ^a
LSD	0.88

Data analysed by two factor ANOVA of bagging treatment and orientation (east/west) with fruit as the experimental unit (n=24). Means with the same letter within each column and section are not significantly different (at p<0.05) as tested by LSD.

Images of the treated fruit show the stronger blush on the east facing fruit, and the reduced blush in bagging treatments that blocked light, particularly paper and Tyvek® (Plate 1). The severe sun damage observed in some fruit bagged in clear plastic is evident (the middle fruit in the top row in the clear plastic - west tray).

Plate 1: 'Honey Gold' mangoes at or near eating ripe grown in east or west orientation at Yelgun, NNSW, bagged using various materials for 4 weeks prior to harvest.



The new bagging materials tested, frost cloth and Tyvek®, did not appear to offer any substantial advantages over paper bags in the present trial. However, weather conditions in the trial were drier than usual. Tyvek® was more rigid, less permeable to water and more resilient to weathering than paper bags, which may have held advantages in wet weather. In contrast, frost cloth was a gentler, softer bagging material, but blocked less light, and hence had minimal impact on blush or red lenticel disorder.

Postharvest light exposure trial

Temperature measurements

The measured temperature within treatment trays was on average slightly higher in the trays exposed to LED lights than in the control trays (Table 10). However, when fruit were not present, these changes were minimal, suggesting that this did not result from heat generated by the LED lights. The higher temperatures may have resulted from physiological changes in the fruit caused by exposure to light, such as increased respiration rate.

Table 10: Temperatures measured within trays treated by LED light exposure, both with and without fruit present.

Treatment	Average temperature (°C) in 12 °C set cold room (fruit present)	Average temperature (°C) in 22 °C set cold room (fruit present)	Average temperature (°C) in 22°C set cold room without fruit
Control	12.7	22.4	22.3
White LED	13.1	23.2	22.4
Blue LED	13.3	23.0	22.5
Intermittent blue LED	13.0	22.8	22.4

Light measurements

The measured light levels under LED lights (Figure 4) were very low compared to pre-harvest light exposure (Figure 3). The blue LED lights showed a strong peak in the blue wavelength range (422-499 nm). However, the light generated was very weak, as was also reflected in single point light readings by

digital radiometer (Table 11). In the previous season, the blue LED lights used gave an average measurement of 1.3 mW/cm², while the lights used in the present season measured at 0.1 mW/cm².

Figure 4: Light intensity spectra at fruit height under postharvest LED light treatments applied within screened trays.

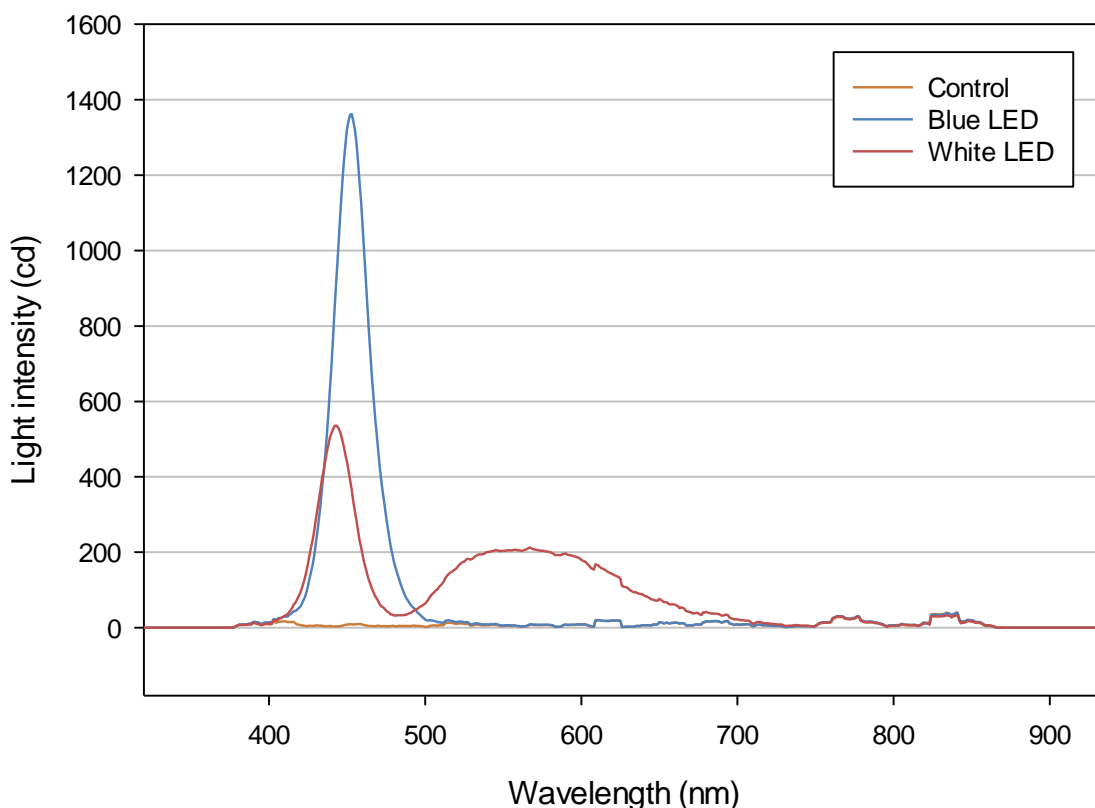


Table 11: Single-point light meter readings under postharvest light treatments at fruit level.

Treatment	Red light (mW/cm ²)	Blue light (mW/cm ²)
Control	0	0
Blue LED	0	0.1
White LED	0	0

Fruit responses to postharvest light exposure

The LED lights used in the trials had limited effect on the fruit, with no significant treatment effects on total blush area or red lenticel score at eating ripe (Table 12). In the previous season, fruit showed a strong blush response to blue light exposure after harvest (Poudel et al., In press). However, the LED lights used emitted a much greater intensity of light compared with the lights used in the present trial. A slight effect was detected in fruit stored at 12°C, where the area of blush on the treated side of the fruit was greater at 3-4 weeks compared with control fruit (Table 13). This result shows the same trend as was observed the previous season, with fruit exposed to constant blue LED light showing the strongest response.

Blush development and red lenticel disorder were both greater in fruit stored at 12°C compared with 22°C. Fruit stored at 12°C tended to show a gradual increase in blush over the storage period (data not shown), presumably due to the ongoing synthesis and accumulation of anthocyanins. In contrast, in fruit stored at 22°C levels of blush remained fairly constant throughout the shorter storage period. Storage temperature could influence postharvest changes in blush through many possible physiological processes, such as anthocyanin generation in response to stress (such as chilling stress (Chalker-Scott, 1999)) and temperature dependent changes in the rates of anthocyanin synthesis and degradation.

Table 12: Effects of postharvest light exposure and storage temperature on blush development and red lenticel score at eating ripe in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Blush (%SA) at eating ripe	Red lenticel score (0-5) at eating ripe
Control	19.3	0.90
White LED	25.8	1.17
Blue LED	22.9	1.10
Intermittent blue LED	22.6	1.00
LSD	7.27	0.42
12°C	29.1 ^a	1.4 ^a
22°C	16.2 ^b	0.7 ^b
LSD	5.14	0.29

Data analysed by two factor ANOVA of light treatment and temperature with tree as a blocking factor and fruit as the experimental unit (n=30-60). Means with the same letter within each column and section are not significantly different (at p<0.05) as tested by LSD.

LED light treatments affected the retention of green skin at eating ripe (Table 1). In fruit stored at 22°C, exposure to blue and white LED light resulted in greater retention of green skin at eating ripe compared to the control. In contrast, fruit stored at 12°C showed greater overall retention of green skin, but exposure to white and blue LED lights reduced green skin retention. Cooler storage temperatures of 12°C have been shown to result in greater retention of green skin in mangoes during ripening (Medlicott et al., 1986). The reduced retention of green skin under LED lights at 12°C may have resulted from more rapid ripening of these fruit. At 12°C storage, the LED light treated fruit ripened more rapidly, as shown in the days taken to reach eating ripe. Similar more rapid ripening on exposure to light has also been observed in banana (Özdemir, 2016). The same effect was not observed at 22°C, with LED lights not significantly affecting the days taken to reach eating ripe. The greater retention of green skin under LED light exposure at 22°C may have resulted from other physiological effects, such as changes in chlorophyll synthesis or degradation.

Table 13: Postharvest LED light effects on retention of green skin at ripe, blush and days taken to reach eating ripe in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Blush (%SA) on treated side at week 3 in 12°C fruit	Green (%SA) at eating ripe in 12°C fruit	Green (%SA) at eating ripe in 22°C fruit	Days to eating ripe in 12°C fruit	Days to eating ripe in 22°C fruit
Control	5.9 ^b	28.7 ^a	1.0 ^b	43.5 ^a	13.3
White LED	10.7 ^a	12.5 ^b	11.5 ^a	35.3 ^c	14.2
Blue LED	14.7 ^a	12.1 ^b	14.8 ^a	36.6 ^{bc}	14.7
Intermittent blue LED	10.8 ^a	21.1 ^{ab}	4.0 ^b	39.1 ^b	13.9
LSD	4.50	9.49	6.65	2.60	1.42

Data analysed by general ANOVA of light treatment with tree as a blocking factor and fruit as the experimental unit (n=15). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

CDS trial

Treatment with CDS induced a strong blush response (Table 14). CDS treated fruit showed an increase in blush area of 20% of the fruit surface from the initial assessment (the day after harvest) until eating ripe, while control fruit blush area increased 6%. The blush was less saturated and darker in colour, as shown by the higher chroma and lower L-values in CDS treated fruit. However, the blush response generated by CDS was typically very patchy and uneven (Plate 2), and was also accompanied by brownish patchy discolouration on the fruit surface. The discolouration suggested damage to the fruit surface that may also have been the trigger for the stress induced synthesis of anthocyanins and

corresponding blush response. In addition, the fruit treated by 50% CDS showed greater retention of green skin colour at eating ripe and slower ripening than the control. Dipping in CDS also resulted in extreme dark lenticel spotting and greater severity of red lenticel disorder (Table 15). Using lower concentrations of CDS, or rinsing the fruit after dipping in CDS may reduce the risk of these damaging side effects.

Table 14: Effect of postharvest dipping in condensed distillers solubles (CDS) on skin colour and ripening of 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Change in blush (%SA) from harvest to eating ripe	Blush chroma at eating ripe	Blush L-value at eating ripe	Green (%SA) at eating ripe	Days to eating ripe
Untreated control	6.1 ^b	53.5 ^b	58.7 ^b	3.9 ^{bc}	10.5 ^{bc}
Water	5.1 ^b	55.4 ^a	60.7 ^a	3.2 ^{bc}	10.2 ^c
Water + surfactant	6.9 ^b	55.1 ^{ab}	60.3 ^{ab}	2.3 ^c	10.5 ^{bc}
25% CDS	20.1 ^a	51.7 ^c	53.9 ^c	8.1 ^b	10.9 ^b
50% CDS	20.7 ^a	49.1 ^d	53.9 ^c	30.5 ^a	11.7 ^a
25% CDS + surfactant	21.4 ^a	51.6 ^c	53.2 ^c	3.6 ^{bc}	10.4 ^{bc}
LSD	6.15	1.61	1.94	5.26	0.63

Data analysed by general ANOVA of CDS treatment with tree as a blocking factor and fruit as the experimental unit (n=25). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

Plate 2: 'Honey Gold' mangoes at or near eating ripe after treatment by postharvest dip with various solutions of condensed distillers solubles (CDS).



Table 15: Effect of postharvest dipping in condensed distillers solubles (CDS) on lenticel disorders in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Dark lenticel score (0-5) at eating ripe	Red lenticel score (0-5) at eating ripe
Untreated control	3.6 ^b	2.2 ^b
Water	3.2 ^{bc}	1.7 ^b
Water + surfactant	3.1 ^c	2.3 ^b
25% CDS	5.0 ^a	3.4 ^a
50% CDS	5.0 ^a	3.2 ^a
25% CDS + surfactant	5.0 ^a	3.1 ^a
LSD	0.46	0.79

Data analysed by general ANOVA of CDS treatment with tree as a blocking factor and fruit as the experimental unit (n=25). Means with the same letter within each column are not significantly different (at p<0.05) as tested by LSD.

MeJA trial

Methyl jasmonate treatment had no significant effect on blush or red lenticel disorder (Table 16). Ethylene treatment slightly increased the change in blush (from the initial assessment the day after harvest to eating ripe), and red lenticel disorder.

No significant effects of MeJA on colour homogeneity were detected (data not shown). Variation between fruit was assessed by comparing the standard deviation of colour values across replicate groups of fruit. Skin colour homogeneity within fruit was assessed by analysing the variability between the 3 background skin measurements on each individual fruit, with no significant treatment effects detected.

Table 16: Effects of methyl jasmonate (MeJA) postharvest vapour treatment on blush and red lenticel disorder at eating ripe in 'Honey Gold' mangoes grown at Yelgun, NNSW.

Treatment	Blush (%SA) at eating ripe	Change in blush (%SA) from harvest to eating ripe	Red lenticel score (0-5) at eating ripe
Control	14.3	4.7	1.3
Vapour control	21.8	5.1	1.7
0.1 mM MeJA	21.7	5.5	1.8
0.3 mM MeJA	18.7	5.3	1.7
LSD	6.74	2.44	0.55
Ethylene	20.9	6.7 ^a	1.9 ^a
No ethylene	17.3	3.6 ^b	1.3 ^b
LSD	4.77	1.73	0.39

Data analysed by two factor ANOVA of MeJA treatment and ethylene (+/-) with fruit as the experimental unit (n=48-96). Means with the same letter within each column and section are not significantly different (at p<0.05) as tested by LSD.

Relationships between blush and red lenticel

Across the 4 trials, the correlations between blush (% surface area) and red lenticel score were analysed (Table 17). There was generally a moderate-strong positive relationship between blush and red lenticel score, indicating that fruit with more blush also tended to show more signs of red lenticel. This relationship was shown at both the initial assessment (prior to any treatment) and at eating ripe.

The change in blush and red lenticel during storage (from initial assessment to eating ripe) did not show a strong relationship. If increasing blush could mask red lenticel disorder, a negative relationship would be expected between the change in blush and change in red lenticel. Increasing blush would result in a decline in red lenticel disorder. However, this was not the case, with none of the trials showing any negative relationship. The CDS trial showed a weak positive relationship, suggesting that increasing blush tended to be weakly associated with greater severity of red lenticel damage.

The positive association between blush and red lenticel disorder in the fruit is likely to be due to the similar triggers and biochemical processes involved. These results suggest that using increased blush to mask red lenticel may not be an effective tool in managing the disorder.

Table 17: The strength of relationships between blush (% surface area) and red lenticel score (0-5) at initial assessment, eating ripe and the change in these variables over time, as assessed in 'Honey Gold' mangoes grown at Yelgun, NSW.

Time	Correlation co-efficient for relationship between % blush and red lenticel score (-1=perfect negative linear, 0=none, 1=perfect positive linear)			
	Bagging trial	Blue light trial	CDS trial	MeJA trial
Initial (day after harvest)	0.42	0.64	0.53	0.76
At eating ripe (ER)	0.65	0.71	0.73	0.78
Change in value (from initial to ER)	0.26	0.17	0.38	0.05

Conclusions

Further experimentation with the use of blue LED lights in enhancing blush would be beneficial. The low light levels emitted by the LED lights used in the present trial limited the effectiveness of the treatment. Experimentation with higher intensity lights would be recommended in future research.

The use of CDS to enhance blush showed some promise, but was hampered by damage to the fruit, including lenticel spotting and brown discolouration. Further research using lower concentrations of CDS, and possibly rinsing after treatment could be of benefit.

MeJA treatment did not show any significant effects on blush, red lenticel or skin colour homogeneity in the present trial. Other trials have shown greater homogeneity of colour in treated fruit, but this effect seems to be inconsistent.

The use of pre-harvest bagging to reduce light exposure appears to be the most reliable technique identified to reduce red lenticel disorder. The benefits of bagging may be even greater under the conditions of heavy rainfall that typically stimulate red lenticel disorder. The commercial adoption of bagging would need to take into consideration the costs, time commitment and the associated reduction in blush. Further experimentation with materials in a wet season would be beneficial in further defining the optimal properties of light blocking, protection from rainfall and ventilation.

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Improving Crop Forecasting

Improving consumer appeal of 'Honey Gold' mango
(MG13016)

Ted Winston, Peter Hofman, Andrew Macnish, Gavin Scurr

(2016/17)

This publication has been compiled by Peter Hofman of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

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Summary

Crop forecasting is an essential tool to help balance fruit supply with customer demand. In a previous project, MG10009, a crop forecasting model based on climatic data was developed for 'Honey Gold' mango. In the present study, the accuracy of this model was evaluated by collecting and processing additional data over 3 years from several farms in the Northern Territory and Queensland.

Accumulation of ≥ 1500 heat sums (at $>12^{\circ}\text{C}$) from full flowering was shown to predict the earliest harvest date of 'Honey Gold' mangoes to within 1-3 weeks of fruit attaining 15% dry matter. Some variation in the model accuracy was observed during the 2015/16 season, whereby the cumulative heat units at the forecast harvest dates were sometimes greater than those indicated at full flowering. This production season was hotter than average and hence the optimal heat sums were reached sooner than predicted.

Harvesting at the Katherine and Burdekin farms usually coincided closely with the accumulation of 1500 heat units. Elsewhere, growers generally started harvesting when fruit had accumulated 1600-1900 heat units or about 1-3 weeks after the original predicted harvest date. This often occurred because growers were trying to remove the fruit of other mango varieties first.

The current study confirmed the reliability of the crop forecasting model parameters. Nevertheless, a mid-season heat sum estimation could help account for hotter or cooler seasons and fine tune the forecasted harvest dates. Although heat sums can forecast the anticipated time of harvest, it is recommended that growers also evaluate fruit for other established indices of maturity before commencing harvest.

Introduction

Accurately forecasting when mangoes will mature and are ready to harvest allows growers and marketers to estimate the start of harvest well in advance and allow better planning of harvesting and marketing strategies and requirements.

Crop forecasting is a significant commercial tool to estimate from each farm the earliest start of harvest based on fruit maturity. This information is a critical aid to match supply with consumer demand (e.g. by strategic timing of specials and advertising), and to better plan infrastructure and labour requirements such as picking crews, harvest aids and transport vehicles. Predicting the start of harvest on each farm based on fruit maturity can be based on measuring environmental conditions that contribute to fruit growth (primarily temperature), and also effective indicators of fruit maturity, e.g. fruit dry matter. Measuring the accumulated heat (e.g. number of degree days above 12°C) from a standard flowering stage onwards to predict the start of harvest has been applied and refined by the Australian mango industry through project MG05004 ("Developing a crop forecasting system for the Australian mango industry"), MG08026 ("Crop forecasting-Queensland grower participation") and MG10016 ("Mango industry capacity building program"). However, the heat sums model in these projects uses the very early "cauliflower" flowering stage as the starting point for measuring heat sums. This stage is less appropriate in the cooler growing areas because of the longer time between the cauliflower stage and harvest. Also, they have done little direct work on the 'Honey Gold' cultivar.

Heat sum or degree trials with 'Honey Gold' mangos were initiated in 2011 in HAL project MG10009 (Improving fruit quality and profitability of 'Honey Gold'™ Mango). This project supported the development of a crop forecasting model for 'Honey Gold' mango, which supplemented the industry wide forecasting model. An accurate crop forecasting model for 'Honey Gold' was developed based on fruit reaching the minimum % DM of 15% at 1,500 accumulated heat sums, from the time of full flowering.

Although sufficient data was collected during project MG10009 to establish the model, ongoing data collection and interpretation is required to increase its robustness and accuracy.

Materials and Methods

The initial crop forecasting model was based on Yan Diczbalis et al. (1999) Crop Forecasting Manual developed under Northern Territory conditions, and using the formula:

$$\text{Heat Sum} = ((\text{daily maximum } ^\circ\text{C} + \text{daily minimum } ^\circ\text{C})/2) - 12^\circ\text{C}$$

12°C is considered the temperature below which mango growth ceases. Tiny Tag temperature data loggers were installed at 10 sites in the Northern Territory and throughout Queensland. It was felt more logical to use stage i (full flower in **Error! Reference source not found.**) rather than the earlier flowering stages suggested in the NT as the starting point for heat sum accumulation. The hotter temperatures in the NT result in flowers progressing rapidly through the flowering stages. However in cooler environments, flowers can pause for some time at the earlier stages before resuming growth, making the estimate of the starting time more difficult. Hence it was agreed that full flowering (stage i) was a more useful starting tool to use in a wider range of environments.

Dates when >50% of the panicles on >50% of the trees reached stage i (full bloom) were recorded. Daily heat sums were then determined and times of predicted fruit maturity and harvest were recorded. Fruit % DM (dry matter) in MG 10009 were determined manually at various stages near maturity and linked to heat unit sums. Data from all growing regions consistently found that 1500 heat units was associated with 15% DM and good eating quality.

The estimated date of fruit maturity is calculated in an Excel spreadsheet by adding the daily heat units until the required heat sum is reached. Initially long term (~25 year) data from the nearest Bureau of Meteorology recording station(s) were used until sufficient on-site data was collected. Initial harvest predictions are made at the time of stage i flowering using long mean term data for each site. The data is refined during the season using current temperature data up until that date, then using the long term means until anticipated harvest time.

The average accumulated heat units per day from three regions are presented in **Error! Reference source not found.**. Different regions may flower at the same time but the date of harvest maturity can vary depending on daily heat units. For example the NT (Katherine and Mataranka) typically have higher daily heat sums than North and Far North Queensland (Mareeba, Mutchilba and Bowen) and SE Queensland (Bundaberg and Wamuran). This is part of the reason for the harvest timing of NT first, then NQ and FNQ, and SEQ.

Figure 1 Average daily accumulated heat units above 12°C for the major 'Honey Gold' growing regions of the Northern Territory (NT), North and Far North Queensland (N&FNQ) and south east Queensland (SEQ).

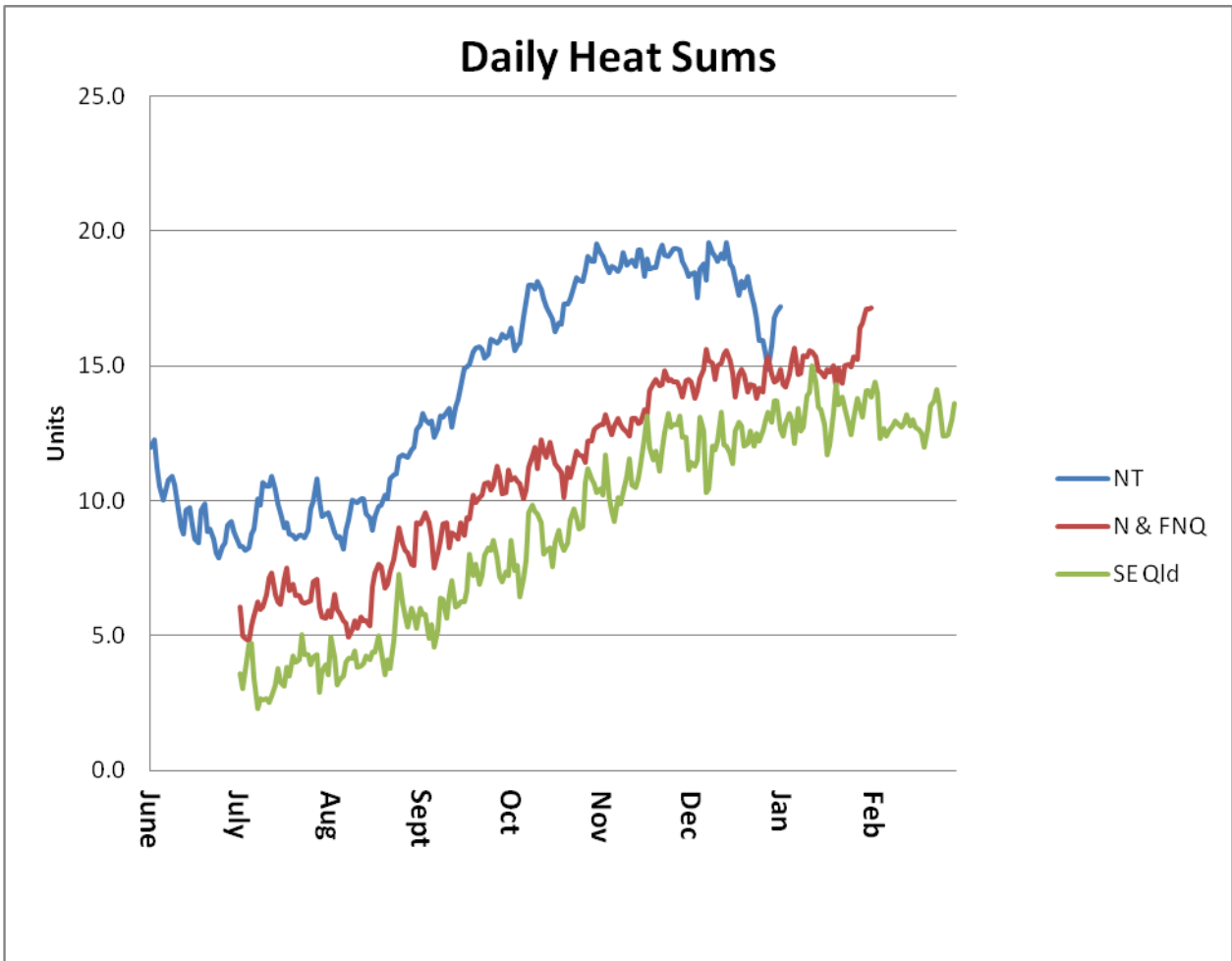
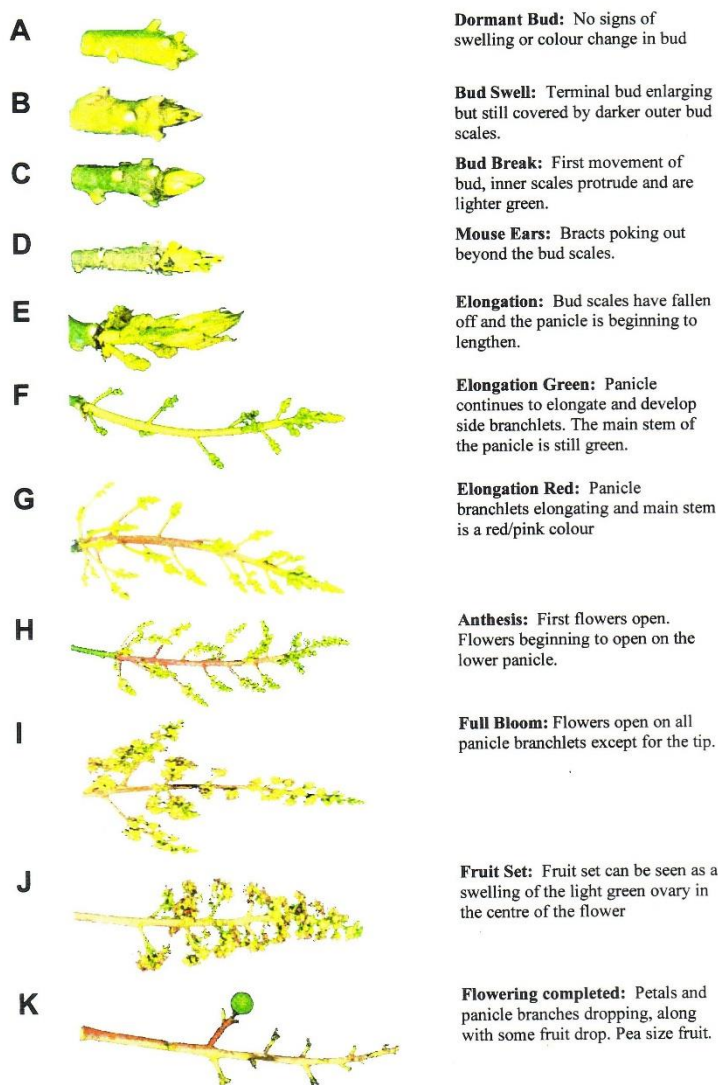



Image 1: Plate 1 Mango flowering stages. Stage i (full flowering) is the starting point for determining heat sums for 'Honey Gold' mango. (Chart from Bally and Homes, Mango Care 2002.)



Results and Discussion

Data gathered over the project has shown that growers generally start harvesting at slightly later times than when fruit reach 1500 heat sum degree (Tables 1-3). The 1500 sum is followed more closely in the early harvest areas of the NT where it is of advantage to get fruit into the market place as soon as they are sufficiently mature but not to harvest immature fruit as has been the case with some other cultivars. Time of 1500 heat units has coincided well with start of harvest. In areas such as Mareeba/Dimbulah harvesting starts at higher heat sums, not because fruit are not ready, but growers are trying to remove their KP and R2E2 fruit first. Mature KP and R2E2 fruit drop when ready, but Honey Gold can hang on longer. Leaving fruit longer on the tree means growers may lose some fruit to drops but remaining fruit gain an extra grade size or more – thus a larger number of trays.

In 2015/16 potential harvest dates (Table 3) were in some instances more advanced than those indicated at stage i. 2015/16 was hotter than average in northern areas thus the optimal heat sums were reached



sooner than normally predicted. Having a mid season estimation helps to take into account hotter or cooler seasons.

Work over 6 years has confirmed that >1500 accumulated heat sums (>12°C) as a good guide for commencing harvesting of Honey Gold mangos. MG13016 has helped to confirm and refine this result. Although heat sums can predict anticipated time of harvest, growers still need to evaluate fruit for the % DM, shape and flesh colour before making the critical decision on when to harvest.

Fruit are ready to harvest when they matured sufficiently to be able to ripen to acceptable appearance (e.g. size, shape, skin and internal flesh colour) and eating quality. The % dry matter (% DM) of the flesh is a good indicator of the potential to achieve acceptable flavour. All maturity indicators (including fruit shape and skin texture) should be met before the fruit are harvested. Research indicated that the minimum harvest % DM for 'Honey Gold' is 15%. (This figure has now been set by AMIA (Australian Mango Industry Association) as the maturity standard for Honey Gold.)

The MG13016 proposal envisaged development of an iPad/iPhone app to allow growers to directly input data into the app which will then be synchronised directly with the Piñata data analysis system. The app would then predict and report approximate harvest times and volume forecasts from each of the growers. This development did not occur as it was felt that the Excel model with some improvements would be sufficient. THC has continued to collect data and provide the forecasting.

It was anticipated that growers would be able to record stage i and then download the loggers and send data to THC or Piñata. Growers have been good in understanding when trees are at stage i and reporting this to THC. However training of growers on downloading the data loggers has proved problematic with numerous issues arising. Piñata on their farms in the final year of the Project have switched to a different logger which give continuous results which can be read by the Mango farm manager at Piñata's home office. Previously readings depended on either the individual farm manager taking them or the Mango Farm Manager or THC visiting Piñata farms to download the Tiny Tag loggers.

The Crop Forecasting model works and can be used for other cultivars across the industry but needed heat sum totals will differ between cultivars. This is something that could be adopted by AMIA in their programme of reducing harvesting of immature fruit.



Table 1. Predicted harvest dates 2014 – 15

Grower/location	Stage i	Predicted harvest at stage i	Predicted harvest mid season	Date 1500 heat units	Date Harvest	Heat units at harvest	Comments
Fox Road Katherine NT	6 Aug	11 Nov	12 Nov	18 Nov	14-18 Nov	1433-1506	
Deans Katherine NT	1 Aug	10 Nov	11 Nov	13 Nov	25-30 Nov	1710-1839	Some data missing Not sure how accurate stage i
Hayes Katherine NT	4 Aug	6 Nov	9 Nov	11 Nov	1-4 Nov	1895-1952	Tree ripe, needed to harvest other farm first
Mataranka NT	6 Aug	17 Nov	19 Nov	23 Nov	4-10 Dec	1718-1830	Need to finish Katherine harvest first
Holloway Giru NQ	6 Aug	12 Dec	12 Dec	12 Dec	13-15 Dec	1517-1548	Used Ayr Research station long term data as no logger
Euri Gold Bowen NQ	28 Jul	18 Dec	18 Dec	18 Dec	19 Dec-9 Jan	1533 at start	Blocks R1 & R 12. Multiple blocks with different flower times
A Zugno Mutchilba FNQ	20 Aug	18 Dec	19 Dec	23 Dec	9-13 Jan	1760-1811	Shelby block. Delay start as need to finish KP and R2E2s
Cetinic Mareeba FNQ	29 Aug	2 Jan	5 Jan	11 Jan	9 Jan	1494 at start	Block 9.
I Pershouse Benaraby CQ	2 Sept	mid Jan	21-26 Jan	16 Jan	26 Jan-6 Feb	1585 at start	Tried on 6 th Jan but white inside. Multiple blocks
Pinata Rockhampton CQ	16 Sept	10 Jan	12 Jan	13 Jan	19-28 Jan	1624-1762	Held back harvest for commercial reasons
Pinata Wamuran SEQ	26 Sept	9 Feb		30 Jan	9 Feb – 2 March	1634-1893	Multiple blocks over 2 farms



Table 2. Predicted harvest dates 2015 – 16.

Grower/location	Stage i	Predicted harvest at stage i	Predicted harvest mid season	Date 1500 heat units	Date Harvest	Heat units at harvest	Comments
Fox Road Katherine NT	28 Jul Main	8-11 Nov	8-12 Nov	10 Nov	17-23 Nov	1651-1761	Used main flowering date
Deans Katherine NT	28 Jul Main	9-13 Nov	9-13 Nov	9 Nov	19-26 Nov	1707-1845	Used main flowering date
Hayes Katherine NT	5 Aug 17 Aug	9-13 Nov 15-18 Nov	11-14 Nov 16-20 Nov	10 Nov 16 Nov	25-30 Nov	1802-1891 1698-1787	Different flowerings in parts of farm
Mataranka NT	17 Aug	24-28 Nov	25-29 Nov	25 Nov	28 Nov-15 Dec	1575-1900	Need to finish Katherine harvest first. Rain events
Holloway Giru NQ	12 Aug	15-20 Dec	15-19 Dec	14 Dec	On time	1508 at start	Used Ayr Research station long term data as no logger
Euri Gold Bowen NQ	~13 Jul	11-17 Dec		10 Dec	8 -27 Dec	1478 at start	Blocks R1 & R 12. Multiple blocks with different flower and harvest times
A Zugno Mutchilba FNQ	17 Aug main	18-23 Dec	19-24 Dec	19 Dec	9-14 Jan	1827-1904	Shelby block. Delay start as need to finish KP and R2E2s
Cetinic Mareeba FNQ	29 Aug	6-11 Jan	6-11 Jan	6 Jan	11 Jan start	1565 at start	Block 9.
I Pershouse Benaraby CQ	21 Aug 7 Sept*	13-17 Jan	13-17 Jan	13 Jan	15-28 Jan	1556-1759	Trap Yard block for logger. *other blocks
Pinata Rockhampton CQ	10 Aug	29 Dec-2 Jan		28 Dec	29 Dec-5 Jan	1524-1645	
Pinata Wamuran SEQ	18 Sept	1-8 Feb	1-8 Feb	1 Feb	9-19 Feb	1607-1725	Held back slightly



Table 3. Predicted harvest dates 2016 – 17

Grower/location	Stage i	Predicted harvest at stage i	Predicted harvest mid season	Date 1500 heat units	Date Harvest	Heat units at harvest	Comments
Fox Road Katherine NT	22 Aug	22-26 Nov	19-21 Nov	18 Nov	24-28 Nov	1649-1738	
Deans Katherine NT	~22 Aug	22-25 Nov			21-25 Nov		Not sure accurately of i. Logger stopped. No data
Hayes Katherine NT	19 Aug	17-20 Nov	13-16 Nov		27-30 Nov		No one down loaded logger
Mataranka NT	22 Aug	27-30 Nov	23-26 Nov	20 Nov	5-10 Dec	1820-1900	Wait for Katherine to finish. Changed logger type mid season
Holloway Giru NQ	28 Jul	9-13 Dec	6-9 Dec	2 Dec	10-12 Dec	1638-1667	
Euri Gold Bowen NQ	8 Aug	22-16 Dec	17-21 Dec		3 Dec-9 Jan		R 12. Multiple blocks with flowering all over the place. Logger not downloaded
A Zugno Mutchilba FNQ	15 Aug	19-23 Dec	14-18 Dec	13 Dec	6-12 Jan	1884-1970	Shelby block. Lots of tree ripes and drops. Delay until KP and R2E2 finished
Cetinic Mareeba FNQ	1 Sept	8-13 Jan	4-8 Jan	29 Dec	6 Jan start	1636	Hot weather advanced
I Pershouse Benaraby CQ	22 Aug	13-17 Jan					No one downloaded logger
Pinata Rockhampton CQ	26 Jul	24-29 Dec	26-30 Dec	21 Dec	1-3 Jan	1678-1707	Heat advanced harvest
Pinata Wamuran SEQ	22 Aug	20-25 Jan		22 Jan	8-15 Feb	1758-1865	Harvest stretched for commercial reason



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