Development of Best Practice Pre- and Postharvest Protocols for Production of Calypso Mango: Phase 2

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Development of Best Practice Pre- and Postharvest Protocols for Production of Calypso™ Mango: Phase II

P.J Hofman *et al.*

Final Report

Agri-Science Queensland, Department of Employment, Economic Development and Innovation, Maroochy Research Station, Nambour Qld 4560

SHS Servicing Horticulture

Queensland Government Department of Primary Industries and Fisheries

one harvest

HAL Know-how for Horticulture™

Development of Best Practice Protocols for production of Calypso™ Mango: Phase II

HAL Project Number: MG06005

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Calypso™ is the first mango commercialised from a structured breeding program in Australia in the last 30 years. Bred and developed at Childers, SE Queensland it is the progeny of 'Sensation' and 'Kensington Pride' and carries the best attributes of both parents. The variety has reliable flowering and is highly productive yielding in excess of 25 t/ha from mature orchards. The fruit is highly coloured with a red blush overlaying a bright yellow skin. The flesh is fibre-free and firm with a distinctive mango flavour. The variety has good tolerance to flower and fruit diseases with extended retail shelf life. In excess of 80% of the crop reaches premium grade, conforming to the preferred colour and size required by Australian retailers. The variety has excellent export potential into Asian, the Middle East and European markets.

The previous three-year research project FR02049 ('Phase I') achieved considerable progress in understanding nutritional requirements, postharvest handling systems, maturity standards, and ripening practices of Calypso™ mango . However, continued development of this variety required additional research to further develop best practice protocols for pre and postharvest management of Calypso™ fruit. Using an integrated supply chain approach to ensure delivery of a consistent high quality product to consumers, the areas investigated in this project include: floral manipulation to improve flowering uniformity and out-of-season flowering; pruning systems for better canopy control and improved fruit quality; further refinement of maturity standards and sorting systems to ensure optimum eating quality; improved harvesting and packhouse operations to minimise quality loss; continual assessment and improvement of commercial ripening and retail practices, including guides for ripeners and retailers in relation to defects and practices to maintain quality, and a quality defects guide for growers; improved practices for export, including market access requirements, improved cold and controlled atmosphere transport systems, and fruit sourcing guidelines for reliable outturn quality on export markets; and production management systems for specific supply chains, with guidelines on production and postharvest requirements for fruit from specific production districts to be sent to specific export markets.

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Disclaimer

1. Media summary

Calypso™ is a new mango variety bred in Queensland and now being commercialised in Australia with production established in the Northern Territory, Western Australia, Queensland and New South Wales. The objective of the project was to establish best production and postharvest protocols for Calypso™ across diverse environments using a "paddock to plate" supply chain focus to sustainably deliver a consistent high quality product to Australian and international consumers. Some agronomic and postharvest issues were addressed in an earlier R&D project (FR02049) on Calypso™ and are reported elsewhere.

Manipulation of flowering to improve the reliability of cropping and to advance fruit maturity was studied along with the impact of pruning on external fruit colour and yield. In orchards near Darwin, autumn-applied trunk scoring and Ethrel® advanced fruit maturity, increased yield and significantly increased grower returns. Post wet season internal pruning of mature trees significantly increased the percentage of red blush on fruit without reducing crop yield. The length of the harvest window was defined during the 2008/09 season and found to be about two weeks in Darwin and Katherine, and three weeks for Bundaberg. This was shorter than expected and may be influenced by season.

Further research was carried out to confirm fruit maturity to optimise ripe fruit flavour and standards set using flesh dry matter (14%), average flesh colour (7) and heat accumulation units (1640 degree days). Near infrared spectroscopy (NIRS) was developed for rapid, non-destructive measurement of fruit maturity on the tree and is now an important commercial tool to determine when to harvest.

Fruit ripening protocols were previously developed, but commercial recommendations were required to ensure fruit are dispatched to the retail stores at the correct ripeness stage. Dispatched when the fruit had just reached full yellow colour would allow fruit to arrive on the shelf with good flavour, and allow adequate shelf life. A skin colour chart has been developed to assist the ripeners.

Further studies were carried out to minimise damage to the fruit skin through the harvesting and postharvest processes. The performance of harvest aids responsible for harvesting the bulk of Calypso™ crop were evaluated and recommendations to reduce skin damage made to the appropriate companies. Impact damage during transport and packing were assessed and recommendations made to minimise the effect on fruit. Several alternatives for postharvest fruit disease control were evaluated and recommendations made for improvements including changes to temperature protocols that would deliver the required specification to fruit to prevent postharvest rots. Retail fruit quality was monitored at store level, resulting in changes to the supply chain into the Northern Territory that delivered a significant improvement in on-shelf product quality.

Postharvest cool storage, controlled atmosphere (CA) storage and the use of SmartFresh^{SM} as tools to prolong transportation life and optimise fruit quality were investigated. In addition, modified atmosphere (MA) created by a semi-permeable film and skin coatings were researched for possible beneficial effects on postharvest fruit quality. Protocols were developed for postharvest storage regimes, with 12°C giving the best result. There were add-on benefits from CA but little value from MA or skin coatings. Protocols were developed for vapour heat treatment to meet the access requirements for the Japanese market. These were lodged with Biosecurity Australia. Irradiation was investigated as a disinfestation procedure, but further research is required to develop a commercially acceptable result.

The R&D program has made a significant contribution to the commercialisation of Calypso™ mango in Australia. Since the start of the commercialisation of Calypso™, annual production has grown to approximately 4,500 tonnes and is expected to reach 25,000 tonnes by the time orchards mature. Results from agronomic and postharvest research have been disseminated through meetings, newsletters and field days and have been readily implemented by all Calypso™ stakeholders. Future R&D should focus on external fruit quality issues, fruit disinfestation (irradiation) for market access and market (domestic and export) development.

2. Technical summary

Calypso™ mango (*Mangifera indica* L) is the first mango from a structured breeding program to be commercialised in Australia in the last 30 years. It was bred at Childers in subtropical Queensland to overcome the inconsistent production of the mainstream variety 'Kensington Pride'. Calypso™ commercialisation in Australia has been done with a supply chain focus, with production being spread from tropical to sub-tropical latitudes to ensure consistent fruit supply over the mango season. At the start of commercialisation, little was known of the genotypic reaction of Calypso™ in different environments from both agronomic and postharvest perspectives. This project provided technical support for the development of this new variety.

From the agronomic perspective this project focussed on floral manipulation to promote early flowering, and pruning to enhance skin colour without loss of yield. At Darwin, our most tropical location, pre- wet season collar-drenched paclobutrazol followed by post wet season (April) trunk scoring combined with 0.1% foliar Ethrel® significantly advanced fruit maturity and increased production and crop returns. Internal and window pruning of mature trees significantly improved the percentage of skin red blush colour (3%) without reducing yield. The length of the harvest window during the 2008/09 season was about two weeks in Darwin and Katherine, and three weeks for Bundaberg. This was shorter than expected and may vary with season.

Further research was carried out to confirm fruit maturity to optimise ripe fruit flavour, and standards set as 90-95% of fruit to be above 14% dry matter and flesh colour 7, as measured by the previously developed "Calypso™ Picking Guide". Near infrared spectroscopy (NIRS) was developed for rapid, non-destructive measurement of fruit maturity based on dry matter and flesh colour. NIRS technology has advanced to the development of a portable handgun that can be used on individual fruit on the tree. The handgun has been used successfully over the past two seasons and is now an important tool in estimating on-tree maturity and developing harvest schedules.

Fruit ripening protocols were previously developed, but clarity was required on what ripeness stage fruit should be dispatched to retailers to optimise the eating experience. A number of recommendations were made, which culminated in the production of a skin colour chart.

Further studies were carried out to minimise damage to the fruit skin through the harvesting and postharvest processes. Harvest aid performance was evaluated and recommendations made to meet the basic criteria of fruit being wet with detergent for 60-90 seconds. Impact damage during transport and packing were assessed. Improved practices recommended include washing field bins after every use to remove dust and grit, and pack fruit as soon as possible after arrival at the pack house. Plastic liners can cause crease marks on fruit, so alternatives are needed. A hot fungicidal spray system for postharvest disease control was evaluated and found to be under specification for control of postharvest rots. Recommendations were made to increase the spray reservoir temperature to 55°C, reduce the distance between spray nozzles and fruit, and improve insulation of the tunnel. Retail fruit quality was monitored at store level, which resulted in changes to the supply chain into the Northern Territory that significantly improved on-shelf product quality.

Postharvest cool storage, controlled atmosphere (CA) storage and the use of SmartFresh^{SM} as tools to prolong transportation life and optimise fruit quality were investigated. In addition, modified atmosphere (MA) created by a semi-permeable film and skin coatings where researched for possible beneficial effects on postharvest fruit quality. Protocols were developed for postharvest storage regimes, with 10-12°C giving the best result, allowing storage for up to three weeks. There were add-on benefits from CA (2% O_2; 3-5% CO_2) that will deliver fruit to Asia at the preferred ripeness and skin colour. There was little value from MA or skin coatings. Protocols were developed for vapour heat treatment to meet the access requirements for the Japanese market. These were lodged with Biosecurity Australia. Irradiation was investigated as a disinfestation procedure, but further research is required to develop a commercial protocol.

Future R&D should focus on external fruit quality issues, fruit disinfestation (irradiation) for market access and market (domestic and export) development.

3. Executive summary

Commercialisation of 'B74', a 'Sensation' x 'Kensington Pride' mango hybrid, began in 1999. Domestic and overseas marketing since then has confirmed that it is highly accepted by retailers and consumers. The owners of the cultivar, the Department of Employment, Economic Development and Innovation (Qld) and Dorrian Farms, appointed One Harvest to manage the commercial development of 'B74' in Australia (now marketed under the trademark of CalypsoTM) and overseas. Trees have been planted in the Northern Territory (NT; at Katherine, and Darwin), Western Australia (WA; at Kununurra and Carnarvon), north Queensland (NQ; on the Atherton Tablelands), south east Queensland (SEQ; at Bundaberg and Childers) and northern NSW. The spread of geographic locations is designed to provide marketing continuity over several months of the year. At the start of this project, all production and postharvest knowledge of Calypso™ was confined to fruit produced in the SEQ region (internal QHI reports published by A.W. Whiley and P.J. Hofman) where the cultivar was bred. However, strong environmental x genotypic responses are known to occur within mango (Schaffer *et al*. 2009) and evidence of this emerged with Calypso™ as different regions came into production.

The previous three-year research project FR02049 ('Phase I') achieved considerable progress in understanding crop nutritional requirements, postharvest handling systems, maturity standards, and ripening practices. However, to further develop best practice protocols for pre- and postharvest management of Calypso™ additional research was required. The Phase II project used an integrated supply chain approach to identify further R&D required to ensure delivery of a consistent high quality product to consumers. This Executive Summary identifies key results and integrates these across the areas of investigation. The main body of the report (Chapter 4 onwards) provides the detail of the R&D process that produced the results incorporated into the Executive Summary.

3.1. Developing consistent supply of quality fruit, and extending the season

3.1.1. Flowering manipulation and pruning systems

Mango fruit production in the NT can occur all year round due to high ambient temperatures however due to disease issues it is not practical to have trees flowering during the wet season (December-March). Flowering normally occurs during June/July however there is an opportunity to advance flowering to April/May resulting in early fruit production. Research in 'Phase I' of the project showed that foliar sprays of Paclobutrazol and strategically timed trunk-scoring could induce early flowering in the Darwin area however results across years were not consistent. Further research was required to refine treatment times, to evaluate other PGR's in combination with pruning strategies and to test the technology in a less tropical environment.

As mature Calypso™ orchards were not available during 'Phase I', pruning research was confined to tree shaping. However, as trees become larger effective pruning strategies are required to maintain orchard production and quality fruit. Large mango orchards are usually mechanically pruned but this invariably leads to a reduction in orchard productivity. With more mature Calypso™ orchards, it was proposed that research in this project examine combinations of mechanical (tree height maintenance only) and hand pruning and test the commercial outcomes.

Research in this project has shown significant commercial value in applying trunk scoring and foliar Ethrel® to Calypso™ trees at Darwin (NT) both from the point of view of producing earlier, higher-valued fruit as well as improving overall crop yield. In addition, internal pruning of mature orchard trees improved fruit blush without reducing yield. Other benefits from internal pruning are

the opening up of tree canopies to allow better penetration of pesticides and an improvement in the ease of picking fruit. At Dimbulah (NQ) internal pruning improved the pack-out grade of fruit which results in higher returns for the product. However, trunk scoring and/or Ethrel® application don't appear to have any commercial benefits at this location.

3.1.2. How long will the fruit hang on the tree

Delaying the start of harvest can improve the flavour and size of Calypso™ fruit. However, delays may reduce the harvest window and result in crop/quality loss from fruit drop, fruit colouring on the tree (over-mature), sunburn, bats and bird damage, skin sensitivity to harvesting treatments (increasing lenticel spotting etc), increased off-flavours, and internal disorders such as stem end cavity and soft nose.

Little work had been done to determine how long Calypso™ fruit can remain on the tree without significant loss although casual observation suggested the fruit may hang longer than initially thought. To test this fruit were randomly sampled from tagged trees every 1-2 weeks in Darwin, Katherine and Bundaberg in the 2008-9 fruiting season and external and internal quality assessed. Fruit drop and its causes, tree yield, fruit maturity, and the percentage of fruit in 1st, 2nd and processing grade were recorded at harvest. Fruit quality was assessed when ripe. In addition, ReTain® a product that delays fruit maturity of temperate crops and Raynox® reported to reduce lenticel spotting in apples, were evaluated on Calypso™ grown at Bundaberg.

In Katherine and Darwin, fruit drop increased two weeks after the start of commercial harvest and one week later had reached almost 50%. In Bundaberg there was little fruit drop after two weeks but about 30% after four weeks. Harvested fruit in grade one decreased to less than 50% by three weeks (Katherine) and four weeks (Bundaberg) after the start of commercial harvest, mainly because of fruit colouring on the tree. Lenticel spotting increased with later harvests in two of the three sites. Maturity studies in Phase I showed no effect of harvest date on lenticel spotting but fruit were not treated with detergent in those trials compared to this trial. There was no commercially significant effect on fruit from either ReTain® or Raynox®.

The significant fruit drop with later harvests suggests that the commercial window for picking in Darwin and Katherine was about two weeks and for Bundaberg about three weeks in 2008/9. The main factor determining the end of harvest was fruit ripening on the tree. Season may affect the length of the harvest window; however commercial infrastructure requirements and operations need to be planned around the shortest harvest window unless the length of the window can be predicted well before harvest to allow adjustments in harvesting/handling strategy.

Currently fruit with any yellow colour on the skin due to ripening on the tree is considered reject fruit and this was the major cause for downgrading this trial. However, it is worthwhile investigating whether these fruit still have fresh market value and if so may help extend the harvest window by 3-7 days.

3.2. Maximising eating quality to the consumer

Quality and price (value for money) are major determinants of consumer buying patterns (Hewett 2006). In general, external or visual quality determines consumers' initial buying patterns while internal quality will determine future or repeat purchasing habits. Therefore, acceptable and reliable internal quality is essential for maintaining and growing the market for a new cultivar.

Calypso™ has excellent visual appeal. The flesh has good colour and is free from fibre and physiological disorders. However it is milder flavoured than 'Kensington Pride' so it is vital that commercial practices consistently maximise the flavour of Calypso™.

The other major factor influencing flavour is the stage of ripeness at consumption (Gomez-Lim 1997). Work in 'Phase I' provided a basic understanding of ripening changes in Calypso™ and identified the ripeness stage at which maximum flavour occurs. Nutrition and ripening conditions can also have an influence but these are usually minor (see 'Phase I' final report, chapters 5 and 10).

3.2.1. Maturity standards

In mango, starches and other fruit components accumulate during fruit growth and are converted to sugars during ripening, which along with acids and volatile compounds are the major determinants of flavour (Brecht and Yahia 2009). Fruit must attain a certain level of maturity before harvest to ensure that it reach acceptable quality (including flavour) when ripe (Johnson and Hofman 2009). Thus, identifying the stage of maturity that will allow acceptable flavour of ripe fruit is a significant commercial requirement for Calypso™.

In Phase I, some basic understanding of Calypso™ ripening and maturity standards was developed on farms in SEQ during the first two years of the project. The recommendations were then tested in the NT and NQ. Dry matter, Brix and flesh colour of just-harvested fruit as well as heat accumulation units (degree days) were tested to identify potential indicators that combined would provide an accurate harvest guide. Additional testing was required in the 2006/7 season to address potential seasonal and regional variation and to confirm recommendations across the main production districts.

The recommended maturity standards for acceptable flavour of 'Calypso™ developed during 'Phase I' and in this project are summarised in Table 1.

Table 1. The dry matter, flesh colour, Brix, at harvest, and heat units that indicated acceptable flavour of ripe Calypso™ fruit.

District	Year	Maturity indicator			
		Dry matter (%)	Flesh colour[a]	Brix (°)	Heat units
NT	2004/5	13.5	7.0	6.7	1630
	2005/6	13.5			
	2006/7	13.8	6.0	7.0	1650
	Average	**13.6**	**6.5**	**6.9**	**1640**
NQ	2004/5	14.6	6.0	7.2	1620
	2005/6	15.4	5.0	7.6	
	2006/7	13.3	6.2	7.9	1385
	Average	**14.4**	**5.7**	**7.6**	**1503**
SEQ	2002/3	16.0	7.0	7.8	
	2003/4	14.1	7.0	7.3	1820
	2004/5	13.1	7.0	7.2	1680
	2005/6	12.9	6.0	7.0	1540
	2006/7	13.8	5.6	7.7	1300
	Average	**14.0**	**6.52**	**7.4**	**1585**
Overall average		**14.0**	**6.2**	**7.3**	**1578**

[a] estimated colour on the Calypso™ Picking Guide, based on Hue angle measured in 2002/3 and 2003/4

The recommendations for heat units for NQ and SEQ, and flesh colour for SEQ in 2006/07 were lower than recommended from 'Phase I'. This may be related to the unusual non-linear relationship between flavour and these parameters for SEQ.

Using recommendations from 'Phase I' will result in consistently better flavoured fruit which is an important commercial benefit. These standards provided an adequate window between the start of harvest and significant commercial fruit drop to allow harvest to be completed. On this basis, we suggest maintaining the standards recommended in 'Phase I', which are:

- Dry matter of 14%
- Average flesh colour of 7, with no fruit having a flesh colour of less than five
- Brix of 7
- Heat units of 1640

We recommend the industry focus on the three most reliable standards which are dry matter, flesh colour and heat units, and that at least two standards be used in estimating the start of harvest.

The variation in maturity standards between seasons and districts is not surprising given the effect of climatic factors on fruit development. The variation between seasons was generally greater than the variation between regions, which initially suggested insufficient evidence to recommend the use of different maturity standards across production areas. However, in the last two seasons, DM levels higher than 14% were observed at a flesh colour of 7.0 in the NT fruit. This suggests the possibility of a review of maturity standards for the NT with more emphasis on DM as the key maturity indicator. Current recommendations are not to harvest below a DM of 14% even if flesh colour is above 7.0. On the other hand, harvest is possible if DM is 16% or above even if flesh colour is between 6.0-7.0.

In general, the results were typical for mango (Chaplin 1989; Lizada 1991) with DM and Brix increasing with fruit maturity, followed by Brix increasing and acidity decreasing as fruit ripen and reach acceptable flavour (Brecht and Yahia 2009). The increase in flavour with later harvests was expected confirming previous results from 'Phase I' (chapter 6) and was generally noted in all regions. As in 'Phase I', the main factor determining flavour was Brix in the ripe flesh. Flesh acidity had a very weak or nil relationship with flavour. A Brix level of 11.6-12.1° was required for acceptable flavour.

Volatiles were not included in these studies because previous research indicated that Brix is a major determinant of mango flavour and can be manipulated through harvest date. Volatiles are very important in flavour differences across cultivars (Brecht and Yahia 2009) but there is little information of variation in volatiles with harvest date within one cultivar. Future research should concentrate on the relative contribution of volatiles and Brix/acidity to flavour and the potential to improve volatiles and thereby flavour by later harvesting and postharvest practices.

3.2.2. Rapid measurement of maturity – NIRS

Near infrared spectroscopy (NIRS) can be used for rapid, non-destructive assessment of a number of plant constituents (Clark *et al*. 2003; Lammertyn *et al*. 2001). In 'Kensington Pride' mango it can predict % DM in just-harvested fruit and ºBrix of ripe fruit using spectra collected at the just-harvested stage (Guthrie and Walsh 1997). Preliminary results indicated that it could also be effective for Calypso™. Little work had been done in using NIRS at harvest to predict ripe-eating quality, but because of its good prediction of dry matter and the relationship between dry matter and ripe fruit flavour it was expected that NIRS could also predict ripe flavour. If successful, it could provide an additional measure of maturity with the benefit of a non-destructive, rapid system. It could also help to determine fruit maturity of whole blocks or farms before commercial picking,

which is important in cultivars like Calypso™ where there are few distinct changes in external fruit appearance as they reach maturity to allow a selective picking. Thus, further evaluation of NIRS as an additional indicator of maturity and the reliability of a portable hand "gun" were required.

Fruit % DM is an index of the total soluble sugar and starch concentration of the fruit (Brecht and Yahia 2009). The Australian mango industry recommends a minimum DM of 14% at harvest (Meurant *et al*. 1999), which is generally related to sufficient sugars in the ripe fruit to provide acceptable flavour (Subedi *et al*. 2007). Coles (www.coles.com.au) stipulate a quality standard of 14 ºBrix for fruit received to store. Flesh colour also becomes more yellow as the fruit matures, and this can also be used as a quick indicator of maturity.

In 2007/8, the accuracy and usefulness of the handgun for estimating fruit maturity on the tree was further tested in fruit from the three main production regions and populations from several farms within these regions.

The research showed that the commercial "Nirvana" NIRS handgun was very reliable throughout the season and was not affected by fruit/handgun/ambient temperatures or ambient light under NT conditions. Predictability was similar to a static unit designed for use in packing lines. The same DM prediction model could apparently be used for populations in all areas but separate models were required for flesh colour.

The handgun seemed useful for mapping maturity across blocks/orchards and helping identify maturity zones for harvesting. It can also predict ºBrix of ripe fruit from readings taken at harvest but further work is required to confirm this. It may also provide some prediction of ripening time (possibly through % DM).

The results from this work suggest that the handgun was suitable for commercial use and we recommended that this work be done as a separate HAL project (MG08019) to facilitate commercial adoption. The following points were to be considered in further work:

- While results suggest that one DM model can be used for all districts a new DM model could be developed very early in the Darwin season and compared with models from previous seasons to identify season effects. The accuracy of that model in predicting DM and flesh colour in fruit from other farms should then be examined. If required, the information gathered during these confirmations can be used to update the model.
- Growers should be encouraged to use a "maturity zone" concept for determining harvesting schedules. Maturity zones can be predicted in the first instance using flowering date data and these zones tested for fruit maturity using the NIRS handgun. Predicting flesh colour of 10 fruit per tree on about 10% of the trees in the zone will estimate the %DM of the maturity zone to within 0.5 % DM units.
- Sorting of fruit in the pack house for %DM would be a further step in improving flavour uniformity but should be considered secondary to better identifying fruit maturity and maturity zones.

The handgun has been successfully used over the last two seasons and is now a significant tool in estimating on-tree fruit maturity and developing harvesting schedules. We consider that the commercial tools are now available to accurately estimate maturity to provide acceptable flavour to the consumer and no further research is required. The emphasis now must be on encouraging commercial commitment to these standards.

3.2.3. More even maturity

Flowering of Calypso™ mango is relatively easily triggered compared with other cultivars however this phenological event is usually drawn out as shoot tips on trees are at different stages of physiological maturity as they approach the cooler induction months of winter. In most years this leads to a prolonged flowering period which in turn can result in mixed fruit maturity at harvest. It is well documented that foliar applications of Gibberellic acid (GA) made strategically in the autumn and early winter will prevent flowering in mango (Chacko *et al*. 1976; Turnbull *et al*. 1996) due to the maintenance of high endogenous concentrations in vegetative terminals that become floral when exposed to low (≤ 12°C) minimum temperatures. To maintain shoots in a vegetative condition foliar GA applications must be made at intervals less than 6 weeks apart during the floral induction period.

From studies over two consecutive years it was concluded that the interaction between GA concentration and the length of winter induction temperatures (which are not predictable at the time of the GA application) is too finely balanced to produce a predictable and commercially useful result in relation to improving the maturity uniformity of Calypso™ fruit.

3.2.4. Commercial ripening practices

As seen in section 3.2.1, good maturity standards and adherence contribute to improve the mild flavour of Calypso™. In addition, the stage of ripeness at which the fruit are consumed will influence flavour. Reports by consumers of poor Calypso™ flavour could be because of the fruit being consumed under-ripe (too acid) or over-ripe (bland flavour), as well as being too immature. The first two reasons may result from poor consumer knowledge, but the stage at which the fruit are dispatched from the ripener and clear guidelines to retailers and consumers could help overcome this.

Ripening temperature and ethylene recommendations were developed in 'Phase I' (Chapter 10), together with some preliminary studies on the quality of commercially ripened fruit (Chapter 11). Further work was required to identify the ideal stage of dispatch from the ripener to the distribution centre. In addition, fruit that are not consumed quickly enough lose flavour mainly because of decreasing acidity and volatile compounds. Recommendations were required for the ripener and the retailer/consumer regarding the ideal time to consume fruit, together with improved coordination/systems that minimise the length of time in the retail system (which would further reduce the risk of fruit being consumed too late).

To achieve the above requirements fruit from 13 consignments during the 2006-7 season were obtained at the point of dispatch from the ripener, assessed for quality (including flavour) the following day (when the fruit were likely to be placed on the retail shelf) and about every two days thereafter for a further six days.

The results showed there was considerable variation between fruit consignments but useful recommendations were developed to apply to most consignments based on the following results:

- Most fruit that were fully coloured had acceptable flavour although leaving them for several days longer often improved flavour. This was mostly due to decreasing acidity over these few days.
- Consignments with low flavour on receival had relatively low Brix and/or high acidity. Flavour generally improved within 1-2 days because of decreasing acidity.
- There were large differences in Brix between consignments (a range of 12-18°) but there was no change in Brix over the 6-8 days after dispatch. Therefore, the major factor contributing to poor flavour on receival was the higher acidity (slightly under-

ripe) and this was often more obvious in fruit with lower ºBrix, presumably because these fruit were less mature.

- In most cases consignments that had some green colour on the skin also had unacceptable flavour. These fruit achieved acceptable flavour within 1-2 days of receival.

Based on the above the following recommendations were made:

- Ripeners/marketers require guidelines on when to dispatch to the retail store to maximise flavour and the retail chains need to be encouraged to market and sell the fruit as quickly as possible after receival.
- For Calypso™ consumers the most reliable message is: "Consume the day that you buy the fruit. If you need to hold them place in the refrigerator for no more than three days". Any other message based on the fruit reaching a certain skin colour or firmness or holding fruit for a day or two after buying would be confusing and is likely to be misinterpreted.
- Assuming this is the best consumer approach the ripener guidelines should be to dispatch fruit when they have **just** reached full yellow colour (no green fruit remaining in the tray). This would minimise the risk of unripe fruit at retail level and guarantee that the majority of fruit would have acceptable flavour. Fruit are generally sold within 2-3 days of arrival at the retail store by which stage flavour should have increased sufficiently in those with marginal flavour on arrival.
- In instances of suspected difficulty in de-greening because of production practices (e.g. excess nitrogen), firmness should also be used as a criterion to determine when to dispatch to the retailer. A firmness of 2.5-3.0 is recommended.
- Practices that can delay sale from the retail store, such as poor stock rotation at the back of the store and on the retail display, need to be continually assessed and practices improved.
- With early maturity fruit it may be beneficial to hold them one day longer before dispatch to ensure that acidity has dropped sufficiently as the lower Brix cannot "mask" the higher acidity. The risk here is that the less mature fruit may also lose flavour when over-ripe, most likely because the lower Brix cannot compensate for the reduction in acidity and other flavour components in these over-ripe fruit.
- A colour chart for the recommended Calypso™ skin colour for dispatch, including individual fruit and whole trays has been produced and is close to publication.

3.2.5. Understanding flesh changes during ripening

The above work highlighted that a better understanding of ripening changes in Calypso™ was required. The main changes during mango ripening involve softening, a degradation of starches to sugars and a decline in acidity (Brecht and Yahia 2009). Previous work had suggested that less mature Calypso™ fruit take longer to develop acceptable flavour and that flavour can deteriorate if the fruit are held too long. It was unclear what roles sugars and acids play in the development and loss of flavour and whether the interaction between sugars, acidity and flavour changes as fruit mature.

A small trial in 2007 recorded the changes in the external and internal characteristics of Calypso™ fruit during normal ripening using product from the same orchard harvested at early and late

maturity. An iodine spray on the cut surface of the fruit to measure starch levels was also tested as a potential easy indicator of ripeness that can be used by ripeners.

The results showed that Calypso™ fruit from early and late harvests softened at similar rates following ethylene treatment and had acceptable flavour by the time the fruit had reached full yellow colour. Late harvest fruit reached full colour six days after harvest but early harvest fruit required an additional three days to reach full colour (flavour of early harvest fruit was unacceptable by day six).

Late harvest fruit had higher °Brix than early harvest fruit at all stages after harvest (except day one). Also, late harvest fruit had lower acidity than early harvest fruit up to day six. There was little change in °Brix after day six in both the early and late harvested fruit. With early harvest fruit the flavour improved between day six and seven because of reducing acidity. This suggests that acidity is more critical in early harvest fruit as higher °Brix in late harvest fruit may "mask" the negative effect of acidity in non-ripe fruit. Given that there is no change in °Brix during the latter stages of ripening, this parameter does not seem a reliable estimate of when Calypso™ fruit are ripe enough for dispatch from the ripener. Acidity may be a more reliable indicator (particularly in less mature fruit) but is more difficult to measure.

The intensity of purple colour following iodine spray decreased as the fruit ripened. This suggests that an iodine spray to indicate residual starch can indicate flavour but will be influenced by fruit maturity at harvest and acidity in the flesh.

Skin colour is a better indicator of flavour in mature, ripening Calypso™ fruit. This confirms the results of the ripener studies.

3.3. Improving external quality

3.3.1. Harvest aid performance

The skin of Calypso™ fruit is sensitive to damage from sap, detergents, abrasion and impacts and damage becomes more obvious as fruit ripen and age. Most damage occurs during harvesting (Whiley and Hofman 2006). Detergents are used in the harvesting process to reduce sap burn and skin browning by de-activating the damaging components of the sap and/or coating the fruit with a “protective” detergent layer (Johnson and Hofman 2009). However, these detergents can also cause lenticel spotting (O'Hare *et al.* 1999) and this is of particular concern with Calypso™ because of its more sensitive skin. Recommendations were developed in ‘Phase I’ (Chapter 8) regarding detergents to minimise Calypso™ lenticel spotting. This work only considered the effects of detergents themselves on spotting, and not their ability to reduce sap burn and skin browning.

Several harvest aid designs have developed over the years, often with little consideration of how well they adhere to basic fruit handling requirements and little evaluation of their effects on fruit quality. Also, preliminary observations indicated that both design and operation are critical to minimising quality loss during harvesting process (Johnson and Hofman 2009). The “Deliverance" project (MG06007; Delivering mango technology) evaluated several harvest aid designs and operations for other mango cultivars. The current project evaluated the impact of harvest aid design/operation on fruit quality of Calypso™ on two farms in south east Queensland during the 2007-8 season. A new harvest aid design was evaluated at Oolloo Farms, and picking racks with no detergent was compared with modified cherry pickers at Simpson Farms. Bins from both farms were traced from the field to the tray. Based on the results advice was given to designers and operators for improvements. The reports are confidential but the basic recommendations focused on the need to ensure that the fruit are wet with detergent for at least 60 seconds, and preferably 90

seconds. Other recommendations involved design changes to minimise physical damage to the fruit when being "thrown" onto the tarpaulin, and travelling from the tarpaulin to the field bin.

More extensive observations and recommendations were made within the "Deliverance" project reports.

3.3.2. Fruit sensitivity to impacts

During the retail surveys of Phase 1 (Chapter 12) skin marks were often observed on fruit on the shelf. The nature of these marks suggested that the fruit had been exposed to impacts with the damage only becoming obvious as the fruit ripened or sometimes became over-ripe. Initially it seemed most likely that the damage occurred during harvesting and before packing. This type of damage is often not visible during grading but can detract considerably from saleability at retail level (Whiley and Hofman 2006). An understanding of the susceptibility of Calypso™ to impact is important in developing improved practices.

Previous studies on the susceptibility of 'Kensington Pride' mango to impact damage (Ledger 1991) concentrated on flesh damage with no assessment of skin damage. This trial used similar methods to the Ledger study but looked at both skin and flesh damage. Fruit were harvested early in the morning (when they are likely fully turgid and most sensitive to impact) and were given impact treatments immediately after harvest and one and two days after harvest when they were expected to be less susceptible to impact damage.

The skin of Calypso™ was surprisingly resistant to up to a 150 cm drop against a smooth surface but damage would probably increase significantly with impacts against rougher surfaces. There was generally no skin damage immediately after treatment and damage only became obvious by five days as small and superficial light brown streaks or scratches.

Impacts immediately after harvest at heights greater than 75 cm caused more damage to the flesh than to the skin and should be avoided. A two day delay between harvest and treatment significantly reduced skin and flesh damage at 150 cm but had little effect at lower drop heights. Therefore, delayed packing is unlikely to significantly reduce skin and flesh damage because typical commercial packing lines generally do not subject fruit to 100-150 cm drops.

Fruit-to-fruit impacts during normal commercial operations should not cause skin damage. However, fruit-to-stem impacts and contact with sharp edges of the harvest aid and packing line could cause skin marking and this needs to be further investigated.

Subsequent observations showed that dark-coloured crease marks can occur when fruit are loosely packed in plastic liners and road-freighted or when transport conditions caused fruit vibration in trays over long distances. Liners can also cause crease marks in ripe or very ripe fruit if they remain in the inserts for long enough. An alternative to plastic liners is recommended.

3.3.3. High-volume handling systems

The large production expected from new Calypso™ orchards provides challenges for handling high volumes of fruit. One of these is the capital cost of establishing large packing sheds for use for only one month annually. An alternative is to establish one central packing facility to handle fruit from several distant orchards but this would require bulk transport of fruit to the central packing facility. Preliminary trials in 2005/6 indicated that the major challenges with bulk transport are preventing skin damage from abrasion with adjacent fruit and the bin and preventing lenticel spotting. Both of these may be accentuated by condensation on the fruit due to temperature fluctuations during transport and handling which those trials could not conclusively eliminate. Further trials were required to minimise these effects by, for example, providing cushioning

materials between the layers of fruit, "toughening" the skin to minimise expression of damage and minimising condensation on the fruit through good temperature management.

The effect of transportation on Calypso™ quality using fruit grown at Katherine NT in field bins for distances of 30-200 km from field to pack house was investigated. Fruit were harvested using standard commercial practice (harvest aids). In the first trial (early harvest) fruit were placed directly into 350 kg plastic field bins lined (both bottom and sides) with plastic or 1½ corrugated cardboard, or with no lining. In the second trial (late harvest) fruit were placed into 450 kg plastic field bins lined (only bottom) with 1½ corrugated cardboard or thin corrugated cardboard, or with no lining. Fruit from both trials were transported from the farm to pack houses about 30 and 200 km away using air suspension trucks. Fruit were then rated for transport damage on arrival at both locations. Fruit samples were taken from each bin, placed over the packing line, ripened and assessed for damage.

There was little commercially significant damage to fruit transported up to 200 km from the field to the pack house. Most damage would not have resulted in rejection during packing and contributed little to quality loss when ripe. Other observations included:

- Before transport about 5% of the fruit had damage (mostly cuts) associated with harvest confirming the importance of improved design and operation of harvesting systems to minimise mechanical damage (as seen in section 3.3.1)
- Immediately after transport only 13% of fruit showed any damage at the pack house.
- There was more damage when fruit were transported 200 km compared to 30 km but these differences did not translate to unacceptable damage in ripe fruit over either distance.
- Most fruit damage was to the bottom layer in bins (caused by dust and grit) and was significantly reduced by lining bin bottoms with thin cardboard.
- Generally more damage was obvious when there was water or sap involved.
- Removing the stem button from the fruit at harvest did not significantly reduce stem damage to fruit when transported up to 200 km.
- Harvest damage was considerably less in late harvest fruit likely due to greater maturity and hotter weather resulting in less turgid fruit.
- When ripe 15-36% of fruit sampled at harvest had some damage that could be attributed to transport. However, only less than 1% of these fruit had sufficient damage to warrant downgrading.

Improved practices include:

- Washing field bins after every use to remove dust and grit.
- Packing fruit as soon as possible after arrival at the pack house to shorten contact time with water and sap thereby reducing lenticel spotting.
- Lining bin bottoms with thin cardboard to reduce damage.

The first two recommendations are now part of standard operating procedures. The third recommendation proved difficult because water from harvest aids wet the cardboard which caused difficulties when the bins were tipped onto the packing line.

3.3.4. Disease control

Anthracnose (*Colletotrichum gloeosporioides* Penz. and C. *acutatum* Simmonds),and stem end rots (caused by anamorphs of *Botryosphaeria* spp.) are the two main diseases of mango fruit (Johnson 2009). These organisms become established in the fruit during growth and develop as the fruit ripens. Control measures include infield fungicide sprays, orchard hygiene and postharvest treatments. Postharvest fungicide treatments are essential tools in controlling these diseases. In general cold fungicide sprays such as Prochloraz® provide adequate control for anthracnose but a hot fungicide treatment (typically 52°C for five minutes) is generally required to control stem end rots.

Two new approaches to disease control were evaluated in this project. Stem end rots have been more common than anthracnose in the trials in this project suggesting that hot fungicide treatments will be required. Most of these treatments are applied as a hot water dip which are expensive, inflexible and can cause physical damage to the fruit as they pass through the dip. Some comparisons have been made between hot water dips and hot water sprays but these were compared under different treatment conditions (Esguerra *et al*. 2006). There has been increasing use of hot fungicide spray systems in Australia. However, validation of the system has not occurred and assumptions made that fruit reach a similar surface temperature for the required time as in hot water dips. As part of a larger study within the mango "Deliverance" project a commercial hot fungicide spray system used on Calypso™ was evaluated in North Queensland. Hot spray reservoir, spray tunnel and fruit surfaces temperatures were compared with those of a small experimental hot dip system which treated fruit under the commercial conditions of 52°C for five minutes. Fruit samples were taken to determine the disease control efficacy of the two treatments.

Research on other mango cultivars has shown that acidifying the Prochloraz® solution increases its solubility and allows lower concentrations without sacrificing efficacy against Alternaria on mango (Prusky *et al*. 2006). It is possible that this could also apply for anthracnose control. The potential for fungicidal acidification on postharvest disease control of Calypso™ was evaluated.

Hot spray systems

Low disease levels occurred on all fruit from both treatments probably as this was the first crop and the orchard had relatively low disease pressure. Hence comparisons on the efficacy of disease control between the two systems could not be made. However, comparisons between fruit temperatures under both systems indicated that the hot spray system did not heat the fruit surface as much as hot dipping. The hot spray reservoir temperature was set at 52°C but heat loss between the nozzle and fruit surface and to the outside of the spray tunnel resulted in reduced fruit temperatures. The following recommendations were made to help achieve similar fruit treatment conditions as hot dips:

- Increase the spray reservoir temperature to 55°C
- Reduce the distance between the spray nozzles and the fruit
- Improve the insulation around the spray tunnel
- Check the effectiveness of these modifications on fruit surface temperatures

Acidified Prochloraz

Disease incidence was again very low and results indicated there was little difference between Prochloraz® at either low or standard concentrations with or without acidification. The results suggested that acidifying the solution may be of little benefit for the control of Calypso™ postharvest diseases compared with the standard Prochloraz® treatment but further evaluation is required under high disease pressure.

3.3.5. Retailer outturn quality

During the project Calypso™ fruit quality was monitored on the shelves of major retailers in selected capital and regional Australian cities. Standard recording sheets were developed and data collected by lay persons representative of regular consumers. The information was centrally collated by One Harvest staff and used to assess the effectiveness of the supply chain to consistently deliver fruit of a quality acceptable to consumers.

Due to a history of poor quality fruit on retail shelves in the NT (Darwin and Katherine) the supply chain being used was truncated with fruit being taken directly from local pack-houses to a ripening facility in Darwin and then directly distributed to local retail outlets. This resulted in a very significant improvement in fruit quality to NT consumers.

3.4. Transport and storage systems to optimise market returns

3.4.1. Cold, controlled atmosphere storage and SmartFresh^{SM}

Cool storage is important when the delivery time from harvest to the consumer is longer than the typical ripening time (5-10 days) or when at least several days transport is required. Suitable storage temperatures are affected by genetic differences, maturity, duration of storage, delays between harvest and cold storage (and ripeness stage), disease load and fruit tolerance to disease and chilling injury (Johnson and Hofman 2009). Cold storage regimes for Calypso™ were studied during 2006-7 to identify optimum conditions for long-term storage/transport based on previous 'Kensington Pride' results (Nguyen 2003). A short ethylene treatment after removal from storage was tested to try to eliminate the often-observed high acidity in ripe, cold stored mango.

Controlled atmosphere (CA) storage maintains low oxygen (O_2) and high carbon dioxide (CO_2) to further control respiration rate and can have several other advantages such as reduced ethylene production, better flavour retention, slower green skin colour loss and reduced chilling injury (Johnson and Hofman 2009). It can extend the storage life of 'Kensington Pride' fruit by about seven days (Jordan and Smith 1993).

Ethylene promotes ripening in a number of fruit (Saltveit 1999) but can also prematurely trigger ripening. Therefore, controlling ethylene and its effects on fruit ripening can reduce premature ripening and outturn quality. Systems are available to reduce ethylene concentrations in storage facilities but these are generally not considered useful with mango. A more promising strategy is to use 1-MCP (SmartFresh^{SM}), which can be highly effective in delaying ripening by blocking the ethylene effect in a range of fruit including mango (Hofman *et al*. 2001a). SmartFresh^{SM} is used commercially in South Africa when exporting avocados to Europe (Kruger and Lemmer 2007) and is an effective alternative to CA under certain conditions. These systems/strategies needed to be tested on Calypso™ fruit.

The use of CA and 1-MCP in Calypso™ was examined in long and short-term storage experiments. The trial during the 2007-8 season monitored the performance of fruit transported in a CA sea freight container to Europe (without or with applied SmartFresh^{SM}) in addition to determining the storage potential of samples of the same fruit held under similar laboratory conditions for up to five weeks, either in air or under CA of 3% O_2 and minimal CO_2.

Asian markets prefer fruit arriving in a backward ripeness stage and the rapid loss of green colour in Calypso™ after harvest, even at 12°C required additional treatments to ensure that fruit arrived at these markets with at least half green skin colour. Thus, in 2008-9 the addition of high CO_2 concentrations with low O_2 was tested because low O_2 by itself was incapable of retarding green skin colour loss during storage. SmartFresh^{SM} was also included in this trial.

Cold storage regimes (8, 10 and 12°C for 3, 4 and 5 weeks)

At the conclusion of most treatments fruit had about 50% yellow colour but were still relatively firm. Higher temperatures and longer durations resulted in more yellow colour and softer fruit. In most cases cold temperatures alone would not retard yellow skin colour development sufficiently to satisfy Asian importer requirements for backward fruit.

Most fruit had more than 90% yellow skin colour at ripe but did not attain the attractive, full yellow skin colour associated with non-stored fruit. Generally 8°C storage resulted in the least yellow skin colour.

Lenticel spotting and rots were the main factors determining quality loss. Overall the best storage temperature for Calypso™ was 10-12°C, which is similar to recommendations for 'Kensington Pride' (Johnson and Hofman 2009). At 8°C severity of lenticel spotting, stem end rots and flesh acidity can be higher. Storage for longer than three weeks can significantly increase quality loss so more 'robust' fruit from drier regions should be used.

Long-term CA storage

Fruit were fairly soft and coloured upon removal from the CA container (2% O_2, 3-5% CO_2 for 38 days). SmartFresh^{SM} had little impact on either firmness or skin colour at removal. With the sea freight trial 70-100% of the fruit were saleable 2-3 days after removal but this percentage decreased rapidly with time, and less than 20% of the fruit were saleable eight days after removal. This indicates a very short shelf life after removal from storage.

With the static trial, CA (3% O_2, CO_2 below 0.5%) helped retain the green skin colour but also increasing softness compared with air storage. The latter effect has also been reported for the 'Tommy Atkins' mango (Bender *et al*. 2000). Lenticel spotting and skin browning were the major factors determining the end of shelf life. SmartFresh^{SM} increased lenticel spotting on ripe Calypso™ fruit possibly because of the slightly longer time to ripen.

Despite the small effects of CA (no CO_2 control) in static trials it appears advisable that this be used for all sea shipments to the EU because of risks of quality loss.

Results from this research did not support regular use of SmartFresh^{SM} with CA.

Short-term CA with increased CO_2

CA (3% O_2, 5%CO_2) resulted in the less yellow colour at removal after one, two and three weeks storage at 12°C compared with air storage or treatment with SmartFresh^{SM} before storage. This effect was also observed in the long-term trial above and with 'Tommy Atkins' mango (Bender *et al*. 2000). The treatment effect on skin colour was not evident after five days but could allow fruit to be sea-freighted for up to three weeks and arrive in a sufficiently backward state to meet Asian importer requirements.

CA-stored fruit were again softer at removal and full colour compared with air-stored or SmartFresh^{SM}-treated fruit. This is common and is not of a commercial concern with Calypso™ because of the relatively lower acidity in the ripening fruit compared with 'Kensington Pride'.

Ripe fruit quality deteriorated with longer storage times, even with CA treatment. Lenticel spotting was again the main cause for decreased fruit acceptability followed by skin browning and stem end rots. Further understanding of the nature and development of lenticel spotting may help develop control measures to improve the appearance of ripe fruit after storage.

SmartFresh^{SM} at 0.6 or 1.0 ppm had little effect on skin colour or firmness after storage, and is therefore not recommended for commercial use.

In summary, 12°C storage is recommended for Calypso™. Controlled atmospheres at 2% O_2 and 5% CO_2 provide additional benefits, particularly in relation to retarding loss of green colour. Outturn quality and shelf life deteriorates with longer storage so constant attention to quality of fruit going into the container and shortening the time between harvest and the customer is required.

3.4.2. MA and Surface coatings

The use of modified atmosphere (MA) created by a semi-permeable film to restrict the movement of respiratory gases into and out of a packaged product can delay ripening and is a low-cost option to CA (Johnson and Hofman 2009). It can also reduce weight loss (Singh *et al*. 2001), lenticel spotting (Yuen *et al*. 1993) and chilling injury (CI) in mango (Johnson and Hofman 2009).

In addition, some fruit coatings can create an internal MA by restricting O_2 and CO_2 movement into and out of the fruit (Brecht and Yahia 2009). Coatings can improve appearance, reduce water loss, and delay ripening (Johnson and Hofman 2009) as well as reduce mango skin defects such as CI (Bower *et al*. 2003) and lenticel damage (Feygenberg *et al*. 2005).

To test a new MA film supplied by Amcor on Calypso™ fruit at the hard green stage were held at 12°C for three, four and five weeks without or with MA. Fruit was assessed at each removal time for firmness and skin colour, and when ripe for both external and internal quality. Ripe fruit were also stored with or without MA at 7°C for the same duration. In a second experiment fruit were stored at 10 and 12°C for three or four weeks. The quality was assessed several days after removal from cold storage.

The skin of Calypso™ often develops lenticel spotting. It can also be sensitive to dehydration and skin shrivelling especially during prolonged storage. The potential of four different coatings to reduce lenticel spotting and skin aging in Calypso™ was investigated in a small trial in 2007-8 together with its effects on other fruit characteristics including weight loss, firmness, skin colour, °Brix and flesh acidity.

MA

MA resulted in softer and greener fruit when removed from storage after 3-5 weeks. It slightly reduced lenticel spotting and skin browning after five weeks storage but there was little effect on rots. MA did not increase the shelf life after removal from cold storage.

Cold storing ripe fruit for three weeks or longer resulted in severe chilling injury at removal with little effect from MA. As expected, chilling injury was less at higher temperatures and for shorter durations but outturn quality was still unacceptable.

These results suggest that there may be a small benefit of MA for storing hard green or ripe Calypso™ fruit for three or more weeks.

Surface coatings

Fruit treated with carnauba wax had less lenticel spotting and skin browning than untreated fruit or fruit treated with other coatings (including polyethylene wax, beeswax and an organic formulation with olive oil and beeswax). Similar effects of coatings on lenticel damage have been reported in 'Tommy Atkins' mango (Feygenberg *et al*. 2005) suggesting some potential to improve external appearance. All coatings reduced weight loss but also appeared to increase off-odours, which can be a potential undesirable effect of coatings (Johnson and Hofman 2009). Coatings had little benefit in extending shelf life and no effect on flesh °Brix or acidity at eating soft.

There may be some benefit in examining waxes further to control lenticel spotting, but caution is required because of potential negative effects in relation to ripening and off-flavours.

3.5. Market research

Throughout the duration of the project information has been accumulated on various export markets where commercial development is likely to succeed. Target markets where product was sent include: Singapore, Hong Kong, China, The Middle East, Europe, New Zealand and Canada. For all of these destinations Market Access requirements have been research and information developed on preferred fruit specifications, pricing, market access requirements and shipment methods. The information developed by One Harvest is considered confidential.

3.6. Market access

3.6.1. VHT

A vapour heat treatment (VHT) protocol (47°C for 15 minutes) is approved by Japan as a disinfestation protocol for several Australian mango cultivars. A separate submission to Japan is required to gain access of Calypso™ mango into this market however pre- and post-treatment conditions can affect fruit response to the disinfestation treatment (Jacobi *et al*. 2001). A series of VHT experiments were run to prove the technology for Calypso™.

The research showed that there is no significant difference in the heat response of *B. tryoni* eggs when heated in either 'Kensington Pride' or Calypso™ mangoes suggesting that a similar protocol can be used with Calypso™. To verify these results, five large scale confirmatory trials against mature eggs of *B. tryoni* in Calypso™ mangoes were undertaken. Infested fruit were heated to a core temperature of 47.0°C for 15 minutes. Fruit was then water cooled until the core temperature of fruit was ≤ 35°C. No survivors were recorded from an estimated 70,320 treated insects. These treatments had no negative effect on external or internal fruit quality.

A report including these results has been submitted to the Biosecurity Australia for use in future negotiations on the use of VHT on CalypsoTM mangoes for access into the Japanese and other fruit-fly sensitive markets.

3.6.2. Irradiation

Disinfestation treatments are required for marketing in southern Australian states and also for export markets such as New Zealand and the USA. It is likely that the current chemical disinfestation treatments for interstate trade will be banned, and the VHT protocol currently approved for several export markets is expensive. Irradiation is a potentially useful disinfestation treatment against fruit fly and seed weevil in mango that can be used for these markets (Johnson and Hofman 2009). Small refrigerated shipments of Calypso™ to New Zealand in the past few years have arrived with significant skin damage and irradiation was implicated as the major cause. Given the potential benefits of an effective irradiation protocol further work was warranted to identify causes of irradiation damage, and develop effective commercial treatments.

Several trials were conducted in 2007-10. The first trial looked at the effects of fruit holding conditions before and after treatment including harvesting/packing, fruit temperature and time after harvest. Conditions before and after treatment affect mango fruit responses to heat (Jacobi *et al*. 2001) and it was thought that similar processes might occur with irradiation.

The second trial focused on which parts of the commercial harvesting and packing process might increase fruit sensitivity to irradiation. Because the first two trials suggested that irradiation reduced the rate of green colour loss from the skin, the third trial studied whether this could be overcome by treating fruit at different ripeness stages. Typical dose ranges of 369-628 Gy were used. In 2009-10 the response to typical disinfestation doses were studied, including the effect of farm and growing region. The effects of different water soloutions were investigated because of the role of water in

increasing lenticel sensitivity to irradiation. The effects of brushing and wax coatings were also studied in more detail.

Irradiation significantly reduced visual quality of commercially picked and packed fruit, mainly because of increased lenticel damage and skin browning. Similar responses have been observed with 'Kensington Pride' (Boag *et al*. 1990; Johnson *et al*. 1990; McLauchlan *et al*. 1990). 'B74' fruit from some farms were damaged at doses below 100 Gy, while fruit from other farms required more than 200 Gy before the skin was damaged. This indicated that 'B74' was very susceptible, but that production practices can affect fruit response. Also, fruit desapped on racks without any exposure to commercial picking and packing practices showed no increase in lenticel spotting and skin browning with irradiation. This suggests that standard picking and packing processes increase fruit sensitivity to irradiation. Subsequent trials confirmed that fruit sensitivity (primarily to lenticel damage) increased progressively as the fruit passed through the harvesting and packing stages. The effect of the picking and packing processes on lenticel spotting was even evident without irradiation and has been observed in studies with other mango cultivars (Oosthuyse 1999; Self *et al*. 2006). Dipping in de-ionised water for 10 sec increased lenticel sensitivity to irradiation, and the detergent solution used in the harvest aid increased sensitivity further. In addition, brushing in the packhouse in the absence of water had little effect on lenticel damage after irradiation, but brushing with water did. These results suggest that exposure to water and water contaminants are major causes of increased lenticel sensitivity to irradiation. This requires further investigation to identify the specific factors involved.

Cold treatments before or after irradiation also increased lenticel spotting and skin browning compared to irradiating without pre- or post-treatment. However, the effects were so small that pre-treatment conditions were not considered to be a major influence in Calypso™ sensitivity to irradiation.

Irradiation significantly reduced visual quality by increasing lenticel damage within 2-3 days of treatment. Lenticel damage severity in these fruit did not increase any further with ripening or ageing of fruit, while non-irradiated fruit took a further 10 days to reach the same lenticel spotting severity. This suggests that irradiation causes a very rapid ageing of lenticels. Recent studies (Bezuidenhout 2005; du Plooy *et al*. 2006) suggest that lenticel damage may be a stress-related defence mechanism to protect against foreign particles and infections entering the fruit through lenticels. It is possible this mechanism was involved in the current studies.

The lenticel damage appeared to be due to production of dark pigments in the cells around the lenticels. The discoloration penetrated several cell layers into the skin. Waxing the fruit reduced lenticel damage after irradiation, but also retarded green colour loss during ripening. Further studies may develop a waxing treatment with an acceptable balance between reducing lenticel damage without affecting other ripening changes.

In all experiments irradiation retarded loss of green colour far more than softening so fruit maintained an unattractive green/yellow colour for longer and only reached full yellow just before eating soft. Similar effects of delayed colour loss have been reported with 'Kensington Pride' (Johnson *et al.* 1990; McLauchlan *et al*. 1990). Irradiating partly coloured fruit helped to minimise the negative effects of irradiation on green colour loss, but fruit had to be about 60% yellow colour before this effect was significant. Irradiating partially ripened fruit also reduced lenticel spotting, possibly because the lenticels had partly recovered from the "stresses" induced during picking and packing.

Overall, the results indicated that irradiation at disinfestation doses of commercially picked and packed Calypso™ mango is not recommended at this stage given the inconsistency in fruit response. However, as shown above, the trials identified several R&D areas to help develop a

commercial protocol. In addition, a literature review on the responses of mango fruit to irradiation was conducted and provided some key information for further investigation: other mango cultivars develop similar damage from irradiation as 'B74', but 'B74' appears to be more susceptible; those cultivars that can maintain lenticel integrity during fruit expansion, and which have a smaller lenticel cavity and better cuticle coverage of the lenticel, can have less lenticel damage (this has not been confirmed with Australian cultivars and with irradiation); in 'B74', lenticel damage usually involves brown discolouration around the lenticels, but it is not clear why or how these pigments develop (several theories have been proposed); field factors such as rain and humid conditions before harvest contribute to lenticel damage, but other unknown field factors are also involved since farm differences exist in dry production areas; there was no discussion in the literature about how water can increase lenticel damage; other postharvest practices such as holding temperatures, fruit coatings and antioxidants to prevent brown pigment development may help reduce irradiation damage.

3.7. Technology Transfer and Training

Project results were conveyed to all stakeholders each year of the project with speakers from all project collaborators taking part, i.e. Sunshine Horticultural Services, Queensland Department of Primary Industries and Foresty and One Harvest. For the duration of each growing season One Harvest produced an e-newsletter "Calypso™ Catchup" that was emailed to all stakeholders every 7-14 days depending on the volumes of fruit passing through the system and the occurrence of important quality issues that needed to be addressed. Additionally, R&D updates were included for use by stakeholders. Rapid-transfer communication links were developed using email, facsimile and weekly phone conferencing.

Three training workshops were provided in August 2007, October 2008 (both presented by Peter Hofman), and in October 2009 (presented by Leigh Barker). The workshops were aimed at improving understanding of mango fruit physiology and ripening practices. The subject areas included mango physiology, what can reduce saleability, ripening practices and ripeness indicators, ripening systems and information tools. Key staff from One Harvest and their agents/ripeners in the major capital cities were present. Follow-up visits to some of the ripening facilities and monitoring of ripening room performance were undertaken. A pre-season field day was also held for the major Calypso™ growers in October 2008.

4. Developing consistent supply of quality fruit, and extending the season

4.1. Effect of floral induction and pruning techniques on yield and skin colour of Calypso™ Mango 2007 & 2008 experiments

4.1.1. Introduction

Sustainable crop security in tree fruits is dependent on consistent and reliable flowering to ensure the opportunity for fruit set and subsequent growth and development. Fruit quality is dependent on a number of parameters which impact from set to maturity and include nutrition, pest and disease control, irrigation, crop load and the light environment under which fruit develops. The latter is particularly important if fruit is required to develop blush on the skin since the accumulation of anthocyanin is a direct response to sunlight.

The production of mangoes in the tropics and subtropics of Australia provides different challenges across the divergent environments where the crop is grown. With the commercialisation of Calypso™ a deliberate strategy was developed to plant trees in locations with sequential maturity extending from the earliest (Darwin) to the latest (Bundaberg) harvest times. The ability to compete for market share with a new variety lies in the availability of a consistent, high quality product delivered to retail shelves every week for the period the commodity is in season. This is dependent on each location where the crop is grown to reliably produce quality fruit over successive years.

Reliable, sustainable production is least secure in the Darwin region primarily due to flowering failure which is quite prevalent with the 'Kensington Pride' variety grown in the Northern Territory. This is because of unreliable floral induction due to insufficient low temperatures during the winter months. Production of mangoes in north Queensland is also fraught with reliability problems due to flowering failure though generally to a lesser degree. The research reported below was carried out to ascertain if the risk of flowering failure could be avoided through providing management inputs known to reinforce the induction signal, i.e. trunk scoring and foliar ethephon and PBZ applications in addition to the standard PBZ collar drench and to measure their impact on crop productivity. In addition, the ability to achieve early flowering and hence maturity at Darwin has high commercial significance since the annual mango season starts in this district and early fruit achieve high market prices.

Mango trees in the tropics produce 2-3 growth flushes per year as the crop is removed early (Oct-Nov) and the wet season and high temperatures encourage growth through into May. Thus trees become very vegetative and control of growth is required as they fill in their allotted space in the orchard. Mechanical pruning (hedging) is practiced with other commercial varieties growing in the tropics but this leads to very dense canopies with poor light penetration and crop productivity. The Calypso™ mango produces a strong blush across the shoulder and cheek of the fruit however, to maximise this trait fruit must have some direct sunlight during growth. As trees grow a greater percentage of the crop will develop within the canopy resulting in poor blush if light is excluded. This research has looked at strategic tip pruning and internal pruning to alter light profiles within the tree with assessments being made on yield and fruit colour at both a site in the tropics (Darwin) and the subtropics (Dimbulah). The subtropical location was chosen to test the methodology in a significantly cooler environment.

4.1.2. Northern Territory research

4.1.2.1. Materials and methods

The experiments were carried out during the 2007 and 2008 fruiting seasons in a commercial orchard at Acacia Hills, about 60 km south of Darwin, NT. Eight-year-old Calypso™ trees grafted to seedling 'Kensington Pride' rootstocks and planted 8 x 3 m apart (412 trees/ha) were chosen for the experiment. The trees were growing in a clay loam soil that is subject to water-logging during the summer wet season. Irrigation through flowering and fruit development was applied by under-tree micro-sprinklers and crop nutrition carried out as per schedules recommended for mango production in the Northern Territory (Blaikie and Cavanagh, 2003; Whiley and Hofman, 2006). Minimum and maximum daily temperatures were recorded with a TinyTalk™ data-logger placed in the orchard in a screen enclosure mounted 1.2 m above ground level to assist with the prediction of fruit maturity (Heat Accumulation Units, Whiley and Hofman 2006).

The experimental design was 10 treatments replicated 22 times. Treatments were started immediately following harvest of the preceding commercial crop in November, 2007 and consisted of postharvest pruning, April 08 trunk scoring, April 08-applied paclobutrazol (PBZ foliar-applied as Payback® at 1%) and April 08-applied Ethrel® as either a 0.08% or 0.1% foliar spray (all April treatments were applied on the 10-11th Apr 08 when the trees had become quiescent). The two pruning treatments were either tip pruning the fruiting shoot immediately postharvest (28th Nov 07) (Plate 1) or internal pruning of trees following the wet season (11th Apr 08) (Plate 2). All trees in the experiment were treated with collar-drenched PBZ at 20 mL/tree immediately postharvest since this has become common commercial practice.

Plate 1 Fruiting shoot tipped (lightly pruned).

Plate 2 Post wet season internal pruning (left) compared with control (right).

In calculating data recorded at harvest the t/ha figure represents all commercially sized fruit harvested from the plots. As some treatments advanced maturity gross returns were calculated for the 2007 crop however no economic assessment has been applied to the data in 2008 due to the significant decline in Australia's 2008/09 mango crop resulting from poor flowering and fruit set. These conditions keep mango prices high throughout the season and there was no significant difference in grower returns for 1st grade fruit over the harvest period of this experiment.

Fruit maturity was defined by flesh colour and the use of a hand-held NIR gun. The estimate of skin blush (%age of skin with red colouration) was made on 40 fruit from each tree (20 fruit from

both the eastern and western sides of the canopy) and the percentage of fruit with greater than 40% of the surface with blush calculated.

4.1.2.2. Results

There was no treatment effect on crop yield however there was a significant increase in gross returns per hectare from trees collar drenched with PBZ shortly following harvest then trunk-scored and foliar sprayed with Ethrel® in April following the end of the wet season (Tmts 7 & 8) (Table 2).

Table 2 Effect of pruning and floral induction treatments on total crop yield and monetary returns of Calypso™ mango growing near Darwin, NT. Values in columns followed by different letters are significant at $P \leq 0.05$ as tested by ANOVA.

Treatments*	**t/ha**	**$/ha**
1. Control – no treatment	20.3	72471.8^{bcde}
2. PH collar drench 15 mL PBZ plus April foliar 0.08% Ethrel®	19.4	70005.3^{cde}
3. PH collar drench 15 mL PBZ plus April foliar 0.1% Ethrel®	18.6	66190.6^{e}
4. PH collar drench 15 mL PBZ plus April foliar 1.0% PBZ	18.8	66969.8^{de}
5. PH collar drench 15 mL PBZ plus post-harvest light prune	20.3	74622.2^{bc}
6. PH collar drench 15 mL PBZ plus post-harvest hard prune	19.1	69853.1^{cde}
7. PH collar drench 15 mL PBZ plus April trunk score & foliar 0.08% Ethrel®	19.4	78731.5^{ab}
8. PH collar drench 15 mL PBZ plus April trunk score & foliar 0.1% Ethrel®	21.4	82000.0^{a}
9. April trunk score	22.0	74429.3^{bcd}
10. PH collar drench 15 mL PBZ plus April trunk score & foliar 1.0% PBZ	20.6	71707.7^{bcde}
LSD ($P \leq 0.5$)	**ns**	**7470.2**

*For treatments 7 and 8 close to 50% of the fruit was harvested in October 2007 when gross wholesale prices averaged $4.80/kg for 1st grade fruit. By November 2007 gross wholesale prices for 1st grade fruit averaged $3.10/kg.

The most effective treatments on the 2008 crop yield was from trees that were trunk-scored and foliar sprayed with Ethrel® at 0.1% in April 08 following the end of the wet season (Tmt 9) (Table 3). There were no significant differences in yield between any of the other treatments except for those trees that were lightly pruned immediately postharvest where yield declined (Tmt 5).

With respect to cumulative yield from these treatments over the two years of the experiment April trunk scoring plus foliar Ethrel® at 0.1% provided the highest yield but was not significantly different to the lesser Ethrel® application of 0.08% (Tmts 8 & 9). The postharvest light prune (Tmt 5) consistently gave the lowest production compared with most of the other treatments.

The internal tree pruning carried out post wet season improved fruit blush registering the highest percentage of fruit with a surface area greater than 40% red colour. Tmt 7 had a significantly higher percentage of fruit in this category compared with all other treatments except Tmt 6 which also was internally pruned (Table 4).

Table 3 Effect of pruning and floral induction treatments on total crop yield of Calypso™ mango growing near Darwin, NT in 2008. Values in columns followed by different letters are significant at $P \leq 0.05$ as tested by ANOVA.

Treatments	Yield	
	2008 (t/ha)	Cumulative 2007-08 (t/ha)
1. Control – no treatment	26.3[b]	46.6[b]
2. April foliar 0.08% Ethrel®	25.7[b]	45.1[bc]
3. April foliar 0.1% Ethrel®	24.0[b]	42.0[bc]
4. April foliar PBZ at 1%.	20.6[bc]	39.4[bc]
5. Postharvest tip prune	17.1[c]	37.4[c]
6. Post wet season internal prune	23.5[bc]	42.6[bc]
7. April trunk score & post-wet season internal prune	26.4[b]	45.8[b]
8. April trunk score foliar 0.08% Ethrel®	28.6[ab]	50.0[ab]
9. April trunk score & foliar 0.1% Ethrel®	33.5[a]	55.5[a]
10. April trunk score & foliar PBZ @ 1.0%.	26.6[b]	47.2[b]
LSD ($P \leq 0.05$)	**6.8**	**8.1**

Table 4 Effect of pruning treatments on the blush expression on Calypso™ mango fruit growing near Darwin, NT. Values in columns followed by different letters are significant at $P \leq 0.05$ as tested by ANOVA.

Treatments	% of fruit ≥ 40% blush
1. Control – no treatment	28.8[c]
2. April foliar 0.08% Ethrel®	32.5[c]
3. April foliar 0.1% Ethrel®	32.5[c]
4. April foliar 1.0% PBZ	32.3[c]
5. Postharvest tip prune	42.0[b]
6 Post wet season internal prune.	51.5[ab]
7. April trunk score & post-wet season internal prune	53.4[a]
8. April trunk score foliar 0.08% Ethrel®	37.8[bc]
9. April trunk score & foliar 0.1% Ethrel®	40.4[b]
10. April trunk score & foliar 1.0% PBZ	44.2[b]
LSD ($P \leq 0.5$)	**9.1**

4.1.3. North Queensland research

4.1.3.1. Materials and methods

The experiments were carried out in a commercial orchard at Dimbulah, about 45 km west of Mareeba on the Atherton Tablelands in North Queensland. Six-year-old Calypso™ trees grafted to seedling 'Kensington Pride' rootstocks and planted 8 x 4 m apart (312 trees/ha) were chosen for the experiment. The trees were growing in a sandy granitic soil typical of mango soils in the district. Irrigation through flowering and fruit development was applied by under-tree micro-sprinklers and crop nutrition carried out as per schedules recommended for mango production in Queensland (Agrilink, DPI Mango Information Kit; Whiley and Hofman, 2006). Minimum and maximum daily temperatures were recorded with a TinyTalk™ data-logger placed in the orchard

in a screen enclosure mounted 1.2 m above ground level to assist with the prediction of fruit maturity (Heat Accumulation Units, Whiley and Hofman 2006).

The experimental design was 7 treatments replicated 10 times. Treatments were started immediately following harvest of the preceding commercial crop in January, 2008 and consisted of the following:

1. Control – centre pruning only (23 Apr 08)
2. Centre pruning & trunk scoring (23 Apr 08)
3. Centre pruning & trunk scoring & Ethrel® (0.1%) (23 Apr 08)
4. Tip (5th Jan 08) and internal (17th Jun 08) prune
5. Tip (5th Jan 08), internal (17th Jun 08) prune & trunk scoring (23 Apr 08)
6. Tip (5th Jan 08), centre & internal prune (17th Jun 08) & trunk scoring (23 Apr 08)
7. Tip (5th Jan 08), internal (17th Jun 08) prune & trunk scoring & Ethrel® (0.1%) (23 Apr 08)

The April and June treatments were applied to quiescent trees. Tip and internal pruning are shown in Plate 1 and Plate 2. All trees in the experiment were treated with collar-drenched PBZ at 5 mL/tree immediately postharvest since this has become common commercial practice.

In calculating data recorded at harvest the t/ha figure represents all commercially sized fruit harvested from the plots. Fruit maturity was defined by flesh colour using the Calypso™ mango picking guide. The estimate of percentage blush was made on 40 fruit randomly selected from each tree where the percentage of skin with a red colour was recorded. To assess packing quality fruit were rated using a 0-5 scale where ≤ 2 were assigned first grade and ≥ 3 assigned second grade. The rating scale was developed using the Calypso™ grade standards chart. Mean values were calculated for each treatment.

4.1.3.2. Results

In this experiment with the exception of Tmt 5 there was little effect from any of the treatments on yield the 2008 (Table 5). Also there was no significant difference on the mean %age fruit blush between treatments. However, for the most part there was a consistent and significant improvement in fruit grade score where trees were internally pruned (Tmts 4-7). The latter is likely due to the reduction of skin damage through rub on internal branches which in this case had been removed. While all trees had some pruning the more severely internal pruned trees for the most part showed no reduction in yield while maintaining an improvement in fruit quality. There was little difference between treatments in the cumulative yield recorded from this experiment (the combined 2007 and 2008 production) (Table 4). The exception was where trees were tip and internal pruned and trunk scored (Tmt 5) which was significantly lower than the other treatments (4.5 t/ha less than the mean of the other treatments).

Table 5 Effect of pruning and floral induction treatments on total crop yield, %age blush and grade of Calypso™ mango growing at Dimbulah, QLD in 2008. Cumulative yield data is also presented for the 2007-2008 crops. Values in columns followed by different letters are significant at $P \leq 0.05$ as tested by ANOVA.

Treatments	Yield 2008 (t/ha)	Cumulative yield 2007-08 (t/ha)	%age blush	Grade Score (0-5)
1. Control – centre pruning only	18.2	28.6	58.9^{ab}	1.4^{c}
2. Centre pruning & trunk scoring	17.4	29.7	44.4^{c}	1.3^{bc}
3. Centre pruning & trunk scoring & Ethrel® (0.1%)	18.3	29.5	62.2^{a}	1.3^{bc}
4. Tip and internal prune	19.2	29.0	50.1^{abc}	1.0^{abc}
5. Tip, internal prune & trunk scoring	15.2	26.9	55.8^{abc}	0.8^{ab}
6. Tip, centre & internal prune & trunk scoring	17.3	26.5	49.7^{bc}	0.9^{abc}
7. Tip, internal prune & trunk scoring & Ethrel® (0.1%)	17.1	27.3	51.6^{abc}	0.7^{a}
LSD ($P \leq 0.5$)	**ns**	**ns**	**13.5**	**0.5**

4.1.4. Discussion

The use of trunk scoring (girdling, cincturing or ringing) in fruit tree crops is widely reported in relation to improving the intensity of flowering and crop yield (Whiley, 2002). These terms are used in horticulture to describe the complete severance of phloem on a limb or trunk of a tree either by a narrow incision or through the removal of strip of bark without damage to the underlying cambium tissue (Noel, 1970). When successfully carried out the wound will produce callus tissue and eventually heal thereby restoring normal physiological functions to the affected part of the tree. The width of the incision varies depending on the time of application and the result that is being sought. The main effect of scoring is the interruption of phloem transport of photoassimilates and perhaps phytohormones between the scored trunk/limb and other parts of the tree. This may result in visual changes to the tree which are most commonly reported as yellowing of leaves, or changes to tree phenology such as earlier flowering and premature leaf abscission on the scored trees/branches (Swarbrick, 1927; Painter and Brown, 1940; Noel, 1970; Ticho, 1971; Davie *et al*., 1995; Hackney *et al*., 1995).

In correctly scored trunks/branches, transport via the xylem is not affected and the flow of water and solutes from roots to leaves continues almost as normal (Kurtzman, 1966; Noel, 1970). However, there have been several studies that report the accumulation of carbohydrates and change in auxin concentrations in tissues above the score due to temporary phloem dysfunction (Mason and Maskell, 1928a, b; Ticho, 1936; Murneek, 1941; Noel, 1970; Tomer, 1977; Davie *et al*., 1995). Carbohydrate accumulation was not measured in these experiments due to the published body of existing data for mango in the technical literature (Davenport and Núñez-Elisea, 1997) however a consistent earlier and heavier flowering was observed in both years in scored trees at the Darwin site suggesting a higher regime of accumulated photoassimilates was driving this high energy-demand event.

Ethylene is a powerful growth regulator in plants having many different effects on growth and fruit development. The effect of ethylene on mango flowering was first reported from the Philippines when floral expression was noted after trees had been exposed to smoke from burnt leaves (Wester, 1920; Borja and Bautista, 1932; Valmayor, 1972). It was later confirmed by Dutcher (1972a, b) that the smoke from smudge fires contained ethylene which stimulated flowering in mango trees. This result together with the first successful use of ethephon (Ethrel®) to promote flowering in mangoes (Barba, 1974; Bondad, 1972, 1976) lead to the hypothesis that endogenous ethylene plays an integral role in the floral inductive process (Barba, 1974; Bondad, 1976; Chadha and Pal, 1986). However, other studies have shown that ethephon is an effective floral promoter for some cultivars only growing under specific conditions found in the low-latitude (≤ 12°) tropics (Chacko and Randhawa, 1971; Chacko *et al*. 1972a, b; 1974a, b; Dutcher 1972a, b; Núñez-Elisea *et al*. 1979; Chen 1985) and is thus unlikely to play a pivotal role in floral induction in mangoes. In these studies the April application of Ethrel® at Darwin resulted in some leaf abscission and yellowing of the foliage retained on the tree within 7-10 days of application indicating a stress reaction. However, at Dimbulah no change in tree appearance was observed.

While both trunk scoring and Ethrel® application had a visual effect on trees at the Darwin site neither treatment in isolation significantly increased tree yield. However, there appears to be a synergistic affect from using both treatments together at this site as the two highest cumulative yields were recorded when trees were trunk scored and sprayed with either 0.08 or 0.1% Ethrel® in April. In 2007 the same treatments advanced fruit maturity by 2-3 weeks which resulted in a significantly higher return per hectare of planted orchard. Neither trunk scoring nor foliar Ethrel® treatments had any significant effect on crop yield at the Dimbulah site. The difference in crop response between these two sites is likely due to differences in crop phenology being driven by significantly different mean temperatures. At the Darwin site trees normally produce a pre-flowering flush as they come out of the wet season (March-April). Flowering on these autumn-produced terminals can begin in late May through to late June depending on the timing of the induction signal. This is only 5-9 weeks after vegetative growth ceased. In comparison, at Dimbulah the time between the cessation of vegetative growth (late march - early April) and flowering (late June-July) is 12-15 weeks. The longer period of quiescence at Dimbulah would allow the tree to accumulate higher levels of carbohydrate reserves than the shorter period at Darwin hence the benefit from trunk scoring at this site would be relatively greater. The differences between the two sites in response to Ethrel® application is also consistent with the literature (Davenport and Núñez-Elisea, 1997) which reports that the most consistent responses to ethephon are at low-latitude sites such as Darwin.

The internal pruning treatments at Darwin significantly increased fruit skin blush without reducing yield compared with the non-pruned trees. However, there was no significant effect on yield from internal pruning at the Dimbulah site and treatment effect on fruit colour was inconsistent. The differences between the two sites is likely due to older, more vegetative trees at Darwin compared to the younger trees at Dimbulah which have not yet grown to orchard maturity. However, internal pruning at Dimbulah did benefit other aspects of fruit quality (Table 3) with fewer downgrading blemishes recorded on fruit from these trees. The Dimbulah site is particularly windy through the spring months when fruit is growing and vulnerable to skin damage. The improvement recorded in grade quality is likely due to the removal of internal wood thereby reducing surfaces for fruit to rub on. It is of commercial significance that this pruning treatment for the most part did not significantly reduce yield at either site.

4.1.5. Conclusions

The research has shown significant commercial value in applying trunk scoring and foliar Ethrel® at the Darwin site both from the point of view of producing earlier, high-value fruit in some years

as well as improving overall crop yield. In addition, internal pruning of trees improved fruit blush without reducing yield. Other benefits from internal pruning are the opening up of tree canopies to allow better penetration of pesticides and an improvement in the ease of picking fruit. At Dimbulah internal pruning improved the pack out grade of fruit which results in higher returns for the product. However, trunk scoring and/or Ethrel® application don't appear to have any commercial benefits.

4.2. Late hanging of fruit to extend the season

4.2.1. Effect of Retain® on maturity of Calypso mango at Bundaberg – 2007

4.2.1.1. Introduction

ReTain™ (aminoethoxyvinilglycine) is an ethylene biosynthesis inhibitor that delays fruit maturation of apples, pears and stone fruit if applied before harvest (Dussi *et al*. 2002; George *et al*. 2006) Typical delays in maturity for these fruit are 3-4 days with ReTain™ applications slowing down the rate of development of maturity indices whilst fruit is still on trees. These indices include background colour and percentage blush with delayed maturity also resulting in increased fruit size. ReTain™ applications to apples reduced the ripening rate of fruit on trees when the degradation of starch in the flesh was measured. This allowed later harvests, since in apples the maturity standard is percentage of starch in the flesh.

If ReTain™ is commercially functional on mangoes there would be some advantage in delaying harvest on some blocks thereby assisting with harvest management since there is limited time to remove fruit once maturity is reach.

4.2.1.2. Materials and methods

Calypso™ trees grafted to seedling 'Kensington Pride' rootstocks growing at Bundaberg were for this experiment. Trees were in their seventh year of cropping and growing on a mounded sandy loam soil. Agronomic practices were as described in the Calypso™ Best Practice Guide (Whiley and Hofman, 2006). The experimental design was a 4 x 6 randomised block with single tree plots and the product was applied to the trees using a Stihl motorised knapsack spray unit. Spreader at 0.1% concentration was added to the tank mix as per label recommendations for the use of ReTain™. The product was applied to the trees two weeks prior to the estimated time of maturity using the treatments listed below:

1. Control.
2. ReTain™ sprayed at 0.4 g/L.
3. ReTain™ sprayed at 0.8 g/L.
4. ReTain™ sprayed at 1.6 g/L.

Treatments were applied on the 27th January, 2007. Fruit were harvested at the start of commercial maturity and were assessed for flesh colour using the colour range developed for Calypso™mango (Whiley and Hofman, 2006), % dry matter (DM), days from harvest to ripening and lenticel spotting using a 0 to 3 rating scale where 0 = nil and 3 = severe. The measurements were carried out on 20 fruit from each tree.

4.2.1.3. Results and discussion

ReTain™ has been successfully used on temperate fruit crops to delay maturity (Dussi *et al*. 2002; George *et al*. 2006) however in this study there was no effect from pre-harvest applications of ReTain™ on any of the maturity indices measured for Calypso™ mango (Table 6). The lack of response in mango may be due to the thick, waxy skin of the fruit and waxy leaves preventing uptake of the product as this has been determined for some foliar nutrient

applications in this crop (Willingham 1998). No further work should be carried out with this product on Calypso™ mangoes.

Table 6 Effect of pre-harvest foliar ReTain™ applications on delaying maturity in Calypso™ mango. Values in columns followed by different letters are significantly different at P ≤ 0.05 as tested by ANOVA.

Treatments	Flesh colour (5-11)	% dry matter	Days to ripening	Lenticel spotting (0-3)
Control	6.0	16.10	14.5	0.92
ReTain™ at 0.4 g/L	6.0	15.75	13.7	0.83
ReTain™ at 0.8 g/L	5.9	16.16	14.7	1.06
ReTain™ at 1.6 g/L	5.9	16.04	14.3	1.52
LSD (P ≤ 0.5)	**ns**	**ns**	**ns**	**ns**

4.2.2. Effect of Raynox® on sunburn and lenticel spotting of Calypso™ mango

4.2.2.1. Introduction

Many fruit crops are subject to heat and light-induced skin disorders that depending on severity will downgrade product. The two most common disorders are caused by either direct heat (a high fruit surface temperature in excess of 52°C) that results in thermal death of cells followed by necrosis or photooxidative sunburn that results in photobleaching of the skin. In Calypso™ the latter is partially reversible with pigmentation returning to the affected area as fruit ripen. However, skin tissue damaged in this manner show high lenticel spot expression that can also lead to the downgrading of fruit. Schrader *et al*. (2008) found that Raynox® applications significantly reduced the heat-induced skin disorders in apples. In the 2008/09 fruiting season a study was carried out to investigate the effects of Raynox® applications on the skin quality of Calypso™ mango.

4.2.2.2. Materials and methods

Seven-year-old Calypso™ mango trees growing in a commercial orchard near Bundaberg in SE Queensland were used for the study. Twenty-four trees with uniform crop load were selected and 12 trees from the group randomly chosen to receive the Raynox® treatment. Raynox® was used at the rate of 25 mL/L of water and applied to runoff. The treatment began approximately 6 weeks prior to harvest before any hot weather events had occurred and the trees sprayed 21 days apart (two applications in total).

At maturity 20 fruit from the north-western sides of trees both from treated and untreated trees were randomly selected and ripened for skin defect analysis. Fruit were rated at both full colour and 7 days after full colour was reached. The following parameters were assessed: 1) fruit firmness was rated on hand pressure using a scale of 0 to 4 where 0 = firm and 4 = ripe/soft; 2) lenticel spotting on a 0 to 4 scale where 0 = nil and 4 = severe; 3) skin browning on a 0 to 4 scale where 0 = nil and 4 = severe; and 4) sunburn which was rated for severity on a 0 to 4 scale where 0 = nil and 4 = severe, and incidence which is the percentage of the total fruit surface affected. Data was analysed by ANOVA.

4.2.2.3. Results and discussion

There were no significant differences between treatments over any of the parameters rated when fruit reached full colour (Table 1). Seven days after full colour the Raynox®-treated fruit were

slightly more firm and had developed slightly more skin browning symptoms than fruit from the untreated control trees. However, there were no significant differences in lenticel spotting or sunburn damage, either severity or incidence, between treatments (Table 7).

The period between the first application of Raynox® and fruit maturity/harvest was unusually mild with many days of overcast weather. This is reflected in the low incidence of lenticel spotting (1.2-1.9) and sunburn damage (10-15% of skin surface) on untreated fruit (Table 7). These mild conditions may have reduced the potential for Raynox® to express an improvement in skin quality over the untreated control. Alternatively, Raynox® may have no effect on reducing heat damage to skin of mangoes as has been shown for apples (Schrader *et al*., 2008). Further evaluation of Raynox® under more intense heat stress conditions is recommended before dismissing this product as a tool to reduce lenticel spotting and sunburn of Calypso™ mango.

Table 7 Effect of Raynox® applications on the skin quality of Calypso™ mangoes grown near Bundaberg, Qld. Values in columns followed by different letters are significant at $P \leq 0.05$ as tested by ANOVA.

Treatment	Firmness (0-4)	Severity (0-4)			Incidence (%)
		Lenticel spotting	Skin Browning	Sunburn	Sunburn
At full colour					
Control	2.80	1.20		0.10	15.0
Raynox®	2.80	1.30		0.10	10.0
LSD (P ≤ 0.5)	**ns**	**ns**		**ns**	**ns**
Seven days after full colour					
Control	3.8[a]	1.9	1.6[b]	1.1	10.2
Raynox®	3.5[b]	1.8	1.8[a]	1.1	12.2
LSD (P ≤ 0.5)	**0.2**	**ns**	**0.2**	**ns**	**ns**

4.2.3. Effect of foliar GA on lenticel spotting of Calypso™ mango

4.2.3.1. Introduction

Gibberellic acid (GA) has been commercially used for many years for delaying rind senescence in citrus fruit (Bevington, 1973; Pozo *et al*., 2000). Since lenticel spotting of the skin of mango fruit is age-related, strategically applied applications of GA may delay skin senescence and reduce lenticel expression which often results in the downgrading of fruit.

4.2.3.2. Materials and methods

Calypso™ trees grafted to seedling 'Kensington Pride' rootstocks growing at Bundaberg were used for this experiment. The trees were in their seventh year of cropping and growing on a mounded sandy loam soil. Agronomic practices were as described in the Calypso™ Best Practice Guide (Whiley and Hofman, 2006). The experimental design was a 5 x 5 randomised block with single tree plots and the product was applied to the trees using a Stihl motorised knapsack spray unit. Agral®, a commercial surfactant at 0.1% concentration was added to the tank mix as per recommendations for the use of Progibb®. The product was applied to the trees three weeks

(8/1/2007) and repeated again one week (27/1/2007) prior to the estimated time of harvest using the treatments listed below:

1. Control
2. GA (as Progibb®) sprayed at 20 ppm 3 weeks prior to harvest
3. GA (as Progibb®) sprayed at 40 ppm 3 weeks prior to harvest
4. GA (as Progibb®) sprayed at 20 ppm 3 weeks prior to harvest and 1 week prior to harvest
5. GA (as Progibb®) sprayed at 40 ppm 3 weeks prior to harvest and 1 week prior to harvest

At commercial maturity 20 fruit per tree were harvested and identified with an indelible pen. Fruit were then run through a commercial de-sapping/harvest aid followed by a pass over a commercial packing line to ensure that it was exposed to all commercial post-harvest stresses. Once across the packing line the fruit was packed in single layer trays and transported to the laboratory for assessment. A sub-sample of fruit was taken from each tree and internal flesh colour measured using the maturity guide developed for Calypso™ mango. Dry matter was then determined on the flesh of these fruit. The balance of fruit was transferred to a controlled temperature room at 20°C for ripening.

Once fruit had ripened they were rated for lenticel spotting using a 0-5 scale where 0 = zero and 5 = unacceptably spotted. The same fruit were kept at 20°C for another five days when they were rated again. A similar measurement was made of skin browning at eating ripe and five days later using a rating scale of 0-5 where 0 = zero and 5 = unacceptably high.

4.2.3.3. Results and discussion

In general there were no significant differences between treatments for any of the characteristics rated (Table 8 and Table 9). However, the exception was where two sprays of GA at 40 ppm were applied which slightly retarded development of flesh colour in this treatment (Table 8). While this could be interpreted as delayed maturity it was not supported by the dry matter data measured on the same fruit (Table 9).

Table 8 Effect of foliar GA applications 3 and 1 week prior to harvest on flesh colour and lenticel spotting. Values in columns followed by different letters are significantly different at $P \leq 0.05$ as tested by ANOVA.

Treatments	**Flesh colour (5-11)**	**Lenticel spotting at eating ripe (0-5)**	**Lenticel spotting 5 days after eating ripe (0-5)**
Control	6.0[a]	2.1	3.5
Foliar GA @ 20 ppm 3 weeks prior to harvest	6.0[a]	2.1	3.9
Foliar GA @ 40 ppm 3 weeks prior to harvest	6.0[a]	2.1	3.3
Foliar GA @ 20 ppm 3 & 1 week prior to harvest	5.9[ab]	2.4	3.2
Foliar GA @ 40 ppm 3 & 1 week prior to harvest	5.8[b]	2.9	3.4
LSD ($P \leq 0.5$)	**0.15**	**ns**	**ns**

Table 9 Effect of foliar GA applications 3 and 1 week prior to harvest on fruit dry matter and skin browning. Values in columns followed by different letters are significantly different at P ≤ 0.05 as tested by ANOVA.

Treatments	Dry matter (%age)	Skin browning at eating ripe (0-5)	Skin browning 5 days after eating ripe (0-5)
Control	15.7	0.7	2.1
Foliar GA @ 20 ppm 3 weeks prior to harvest	15.3	0.4	1.3
Foliar GA @ 40 ppm 3 weeks prior to harvest	15.5	0.6	1.8
Foliar GA @ 20 ppm 3 & 1 week prior to harvest	15.6	0.5	1.7
Foliar GA @ 40 ppm 3 & 1 week prior to harvest	15.5	1.1	1.8
LSD (P ≤ 0.5)	**ns**	**ns**	**ns**

The data from this study is inconclusive and gives no indication that foliar applied GA will delay skin senescence in mangoes. This may be related to the impervious nature of the skin of mangoes as they approach maturity making it difficult to uptake foliar applied products (Willingham 1998).

4.2.4. How long will fruit hang on the tree

4.2.4.1. Introduction

Delaying the start of harvest can improve the flavour and size of Calypso™ mango fruit, and having a longer harvest window will reduce the equipment and staffing needs because of a more prolonged harvest. However, harvest delays may result in crop/quality loss from the following causes:

fruit drop
sunburn
bats and bird damage
skin sensitivity to harvesting treatments (increasing lenticel spotting etc)
increased off-flavours
internal disorders, such as stem end cavity and soft nose.

Little work has been done to determine how long Calypso™ fruit can remain on the tree without significant loss under current commercial practices, although observation suggested the fruit may hang on for longer than initially thought. To test this, fruit samples were randomly collected from tagged trees every 1-2 weeks in Darwin, Katherine and Bundaberg, and external and internal quality assessed. Fruit drop, the causes for fruit drop, tree yield, fruit maturity and fruit quality were recorded

4.2.4.2. Materials and methods

Fruit were collected from Calypso™ farms in Darwin, Katherine and Bundaberg at the start of commercial harvest (week 0), then two weeks later, then another 1-2 weeks later. By the last harvest significant fruit drop had occurred at all sites, and the trials were terminated.

At each farm 30 trees were tagged. The trees were of average yield and had even flowering to ensure fairly similar maturity of individual fruit on the trees. At each harvest, all fruit were harvested from 5-6 randomly selected trees within the trial site. Each tree represented a replication. At each harvest (and occasionally more often), the number of fruit that had dropped from each of the trial trees was recorded, along with the possible causes of fruit drop.

At each farm (except Darwin), the fruit from each tree were separately placed through the harvest aid, the total fruit per tree counted and weighed, then graded into 1st, 2nd and processing grades based on the commercial grading standards. The number of fruit and total fruit weight in each grade was recorded.

Five fruit per tree were assessed for flesh colour and %DM. Near infra red spectroscopy (NIRS) estimates of maturity from 20 fruit per tree were recorded for Darwin and Katherine, using the NIRS handgun calibrated for Darwin and Katherine farms.

Twenty 1st grade fruit from each harvested tree were placed through the commercial packing line, then either road freighted or airfreighted to the postharvest laboratory at the Maroochy Research Station (MRS), Nambour.

To simulate commercial ripening/distribution practice, the fruit were treated with 10ppm ethylene for two days at 20°C, held at 20°C until full yellow colour, held at 12ºC for a further 2-3 days, then placed at 20ºC for another 6-7 days. They were then assessed for external quality using a 0-4 scale (Table 10).

To assess flavour, subsamples of flesh from the cheeks of the fruit were pooled to provide three samples per tree. These samples were presented to the taste panel at three separate sittings throughout the day of tasting. The panel consisted of 12-15 staff at MRS, excluding obviously "atypical" tasters in relation to preferences or ability to adequately distinguish between samples. Fruit samples were rated for flavour based on the following question: "How do you like the sample as a fruit. That is, do not compare it to other mangoes you have tasted, but how do you like it as a fruit itself"?

The following rating scale was used:

1=dislike extremely
2=dislike a lot
3=dislike somewhat
4=dislike slightly
5=neither like nor dislike
6=like slightly
7=like somewhat
8=like a lot
9=like extremely

A rating of at least 5.5 indicated an acceptable flavour.

Brix (º) on the same flesh samples was assessed using an Atago refractometer with temperature correction. Acidity (expressed as % of citric acid) was determined by mixing each combined sample with an electric hand held blender. Five grams of the blended sample was diluted with 75 ml of distilled water before analysis using a Metrohm Titration system.

Table 10. Rating scales for severity of lenticel spotting, skin browning and rots on Calypso™ mango fruit.

Rating	Lenticel spotting	Skin browning, rots and dendritic spot
0	Nil	Nil
1	To 10%	To 3cm^2
2	To 25%	To 6 cm^2
3	To 50%	To 25%
4	> 50%	> 25%

3cm^2 is the size of a 5 cent piece
12cm^2 is the size of a 20 cent piece

4.2.4.3. Results

4.2.4.3.1. Fruit drop and grade

By the second Katherine harvest (two weeks after the start of commercial pick on that site) 14% of the fruit (approximately 4 kg) had dropped (Table 11). The percentage of fruit in first grade had decreased from 94 to 62%, mainly because of fruit colouring on the tree. One week later, fruit drop had increased to 45% with a further reduction in first grade and increase in processing grade. Average fruit weight over three weeks increased by 60 gm.

Similar results were obtained in Bundaberg, but over four weeks (Table 11). In Darwin, significant fruit drop and fruit damage had occurred by three weeks after the start of commercial harvest, primarily because of fruit ripening on the tree and from geese.

The results suggest that the acceptable harvest window (the time between the start of commercial harvest to significant fruit drop or quality loss) for Katherine was about two weeks, and for Bundaberg, about three weeks.

4.2.4.3.2. Maturity

Harvest commenced at Darwin at 15% DM and 7 flesh colour, at Katherine 17.5% DM and 6.5 flesh colour, Bundaberg 14% DM and 6.5 flesh colour (Figure 1). In Darwin and Katherine, %DM and flesh colour increased to the 2nd harvest, but changed little by the 3rd (last) harvest. At these later harvests, it is likely that the more mature fruit had dropped, so that the average %DM of fruit remaining on the tree did not increase over this time. If this is correct, it suggests that the maximum %DM attainable this season was about 19.5% in both districts.

In Bundaberg, both %DM and flesh colour increased at all harvests (Figure 1) possibly because of the reduced fruit drop compared with Darwin and Katherine.

The changes in maturity with harvest were generally similar between actual and NIRS estimated maturity parameters (Figure 1). However, NIRS tended to underestimate %DM and flesh colour with later harvests, compared to measured values.

4.2.4.3.3. Ripe fruit quality

Lenticel spotting severity increased in fruit from later harvests from Darwin and Bundaberg (Table 12). Severity in Katherine fruit was very high from the first harvest on (Plate 3). The reasons for this are not known. There were no consistent harvest effects on skin browning across the three farms. Rots were very low in Darwin and Katherine. In Bundaberg, rots increased with later harvests (Table 13).

As an aside, Darwin fruit were road freighted to the laboratory in loosely packed Mod6 trays with plastic liners. On arrival, these fruit showed significant damage caused by vibration against other fruit (Plate 4). Also, we noted more discrete skin marks that we had previously associated with harvest damage. We believe these were caused by the fruit rolling/vibrating on the relatively hard wrinkles of the plastic liner.

Flavour increased from the first to the second harvest (Figure 2). In Darwin and Katherine the flavour did not increase to the 3rd harvest, but it did increase slightly in the 3rd harvest from Bundaberg.

Brix increased with harvest at all three sites (Figure 2). Acidity increased until the second harvest, but did not change at the 3rd. There was no harvest effect on acidity with Darwin fruit.

These results suggest that delaying harvest for two weeks benefits flavour, but that delaying longer has little additional benefit except in Bundaberg. The Bundaberg benefit may be related to the marginal maturity at the start, leaving more room for improving with later harvests.

Table 11 Effect of harvest date on tree yield, accumulative fruit drop (percentage of fruit at cooperative to the initial numbers on the tree), average fruit weight and percentage of fruit in first, second and processing grade is, of Calypso™ mango growing at Katherine and Bundaberg. Means within columns with letters are significantly different (P≤0.05) as tested by LSD.

Location	Harvest date	Yield/tree (kg)	Cumulative fruit drop (%)	Av. fruit weight (g)	Fruit per grade (%)		
					1st	2nd	Processing
Katherine	11-Nov	44.8	3 [b]	450 [b]	94 [a]	6	0 [c]
	25-Nov	40.4	14 [b]	470 [b]	62 [b]	10	28 [b]
	1-Dec	28.3	45 [a]	510 [a]	40 [c]	15	45 [a]
	LSD	ns	13	30	11.0	ns	11.4
Bundaberg	27-Jan	23.5	1 [b]	420 [b]	73 [a]	23 [a]	3 [b]
	12-Feb	29.6	4 [b]	500 [a]	83 [a]	9 [b]	9 [b]
	25-Feb	22.7	33 [a]	540 [a]	31 [b]	20 [a]	49 [a]
	LSD	ns	10	40	11.3	8.7	11.1

Table 12. Effect of harvest date on the severity of lenticel spotting and skin browning on ripe Calypso™ mango growing at Darwin, Katherine and Bundaberg. Severity was rated at 0=nil, to 4=more than 50% of the surface skin area affected for lenticel spotting, and zero =nil, to 4 = more than 25% of the surface area affected for skin browning. Means within columns with letters are significantly different (P≤0.05) as tested by LSD.

Location	Harvest date	Lenticel spotting (0-4)	Skin browning (0-4)
Darwin	6-Oct	0.7 [c]	0.0 [b]
	27-Oct	1.5 [b]	0.3 [a]
	10-Nov	3.1 [a]	0.4 [a]
	LSD	0.5	0.3
Katherine	11-Nov	4.0 [a]	1.2
	25-Nov	3.8 [a]	1.0
	1-Dec	3.1 [b]	1.4
	LSD	0.3	ns
Bundaberg	27-Jan	1.1 [b]	1.0
	12-Feb	0.5 [c]	0.3
	25-Feb	1.8 [a]	0.6
	LSD	0.3	ns

Table 13 Effect of harvest date on severity of body rot, stem end rot and dendritic spot on ripe Calypso™ fruit grown at Bundaberg. Severity was rated at 0=nil, to 4=more than 50% of the surface skin area affected for lenticel spotting, and zero =nil, to 4 = more than 25% of the surface area affected for skin browning. Means within columns with letters are significantly different (P≤0.05) as tested by LSD.

Harvest date	Severity (0-4)		
	Body rot	Stem end rot	Dendritic spot
27-Jan	0.18 [b]	0.20 [b]	0.07 [b]
12-Feb	0.40 [b]	0.65 [a]	0.17 [b]
25-Feb	0.83 [a]	0.94 [a]	1.60 [a]
LSD	0.27	0.35	0.18

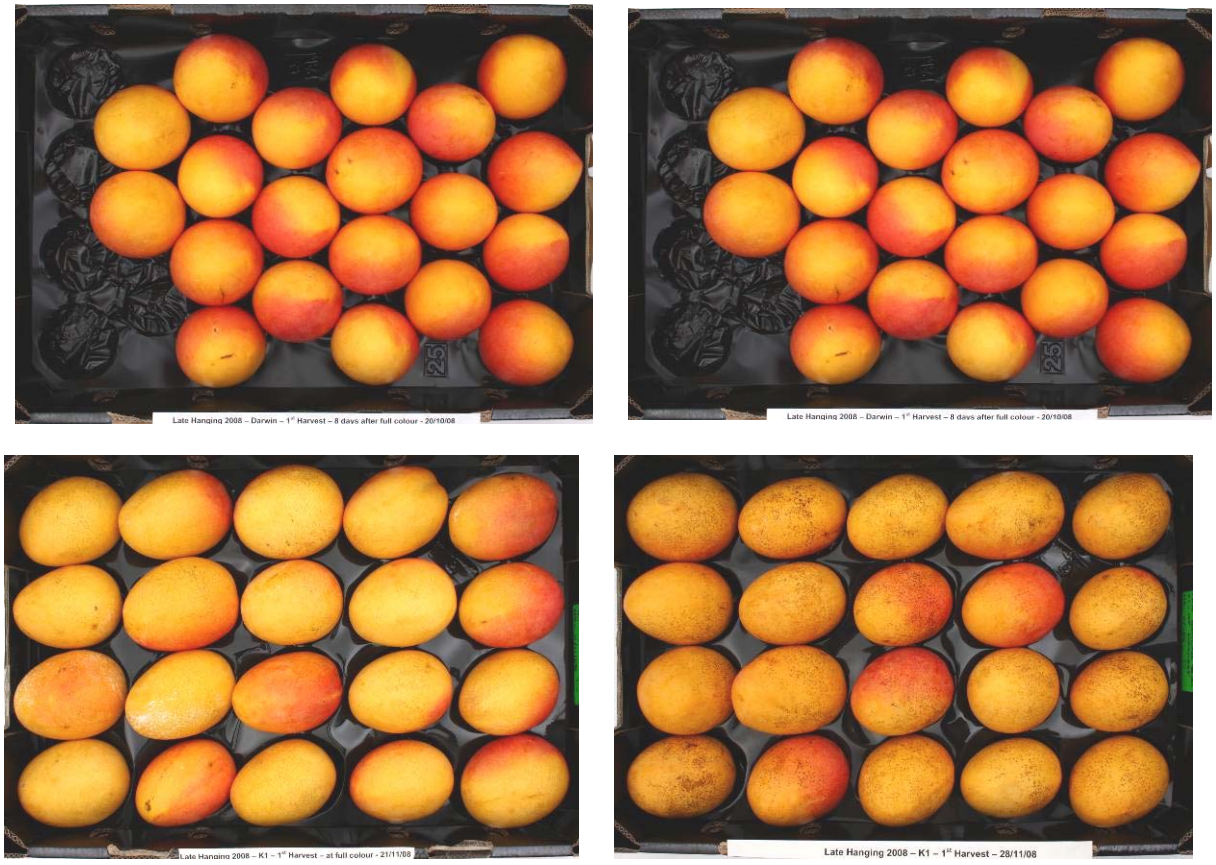


Plate 3 Calypso™ mango fruit from the first harvest from Darwin (top) and Katherine (bottom). Note the significant lenticel spotting on the Katherine fruit, both at full yellow colour (left) and 7-8 days later (right).

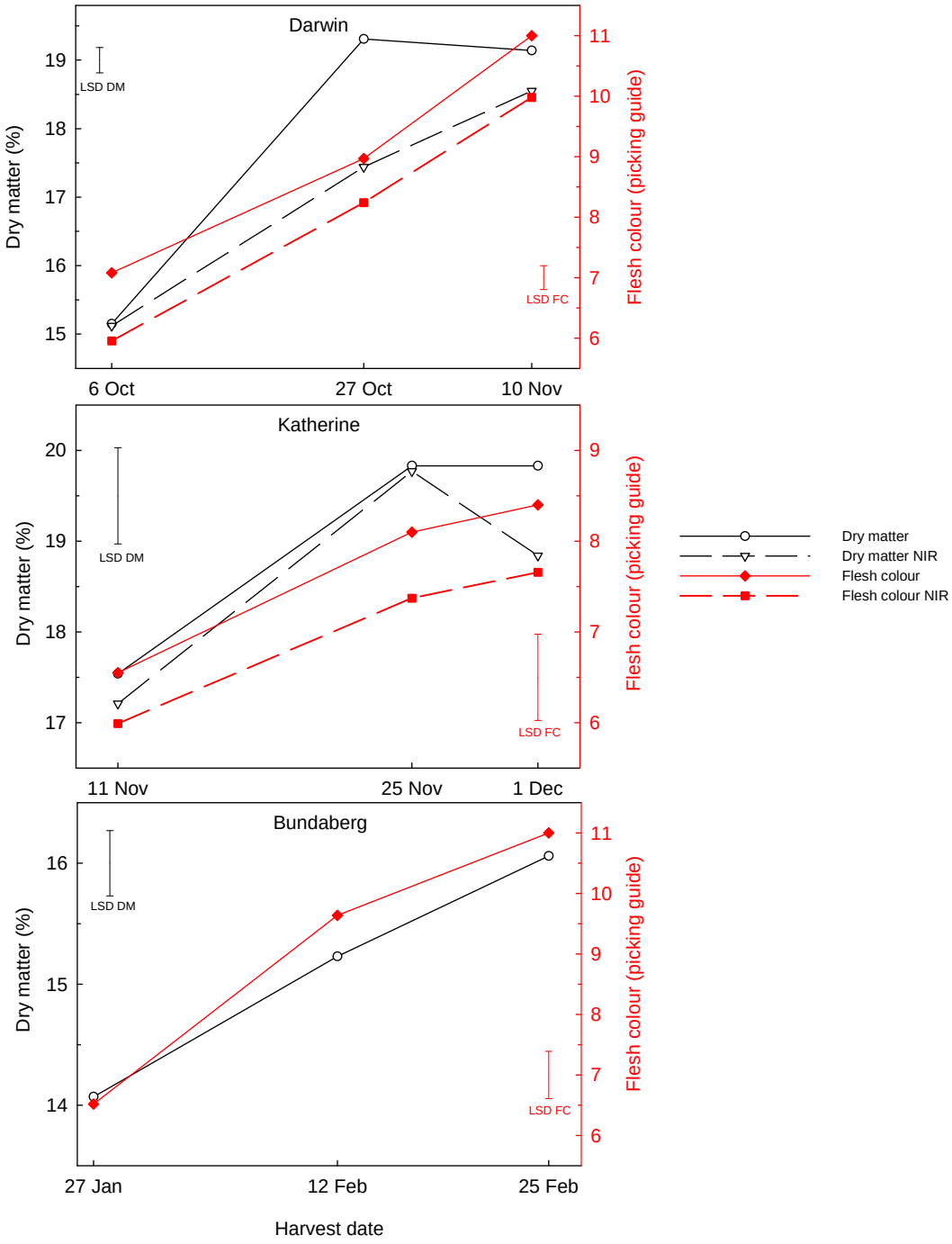


Figure 1 Effect of harvest date on the percent dry matter and flesh colour (scale of 1-11) of harvested Calypso^{TM} mango growing at Darwin, Katherine and Bundaberg. Dry matter and flesh colour was also estimated using the NIRS handgun. Treatment means have to be greater than the vertical bar (LSD) to be statistically significantly different at 95% probability.

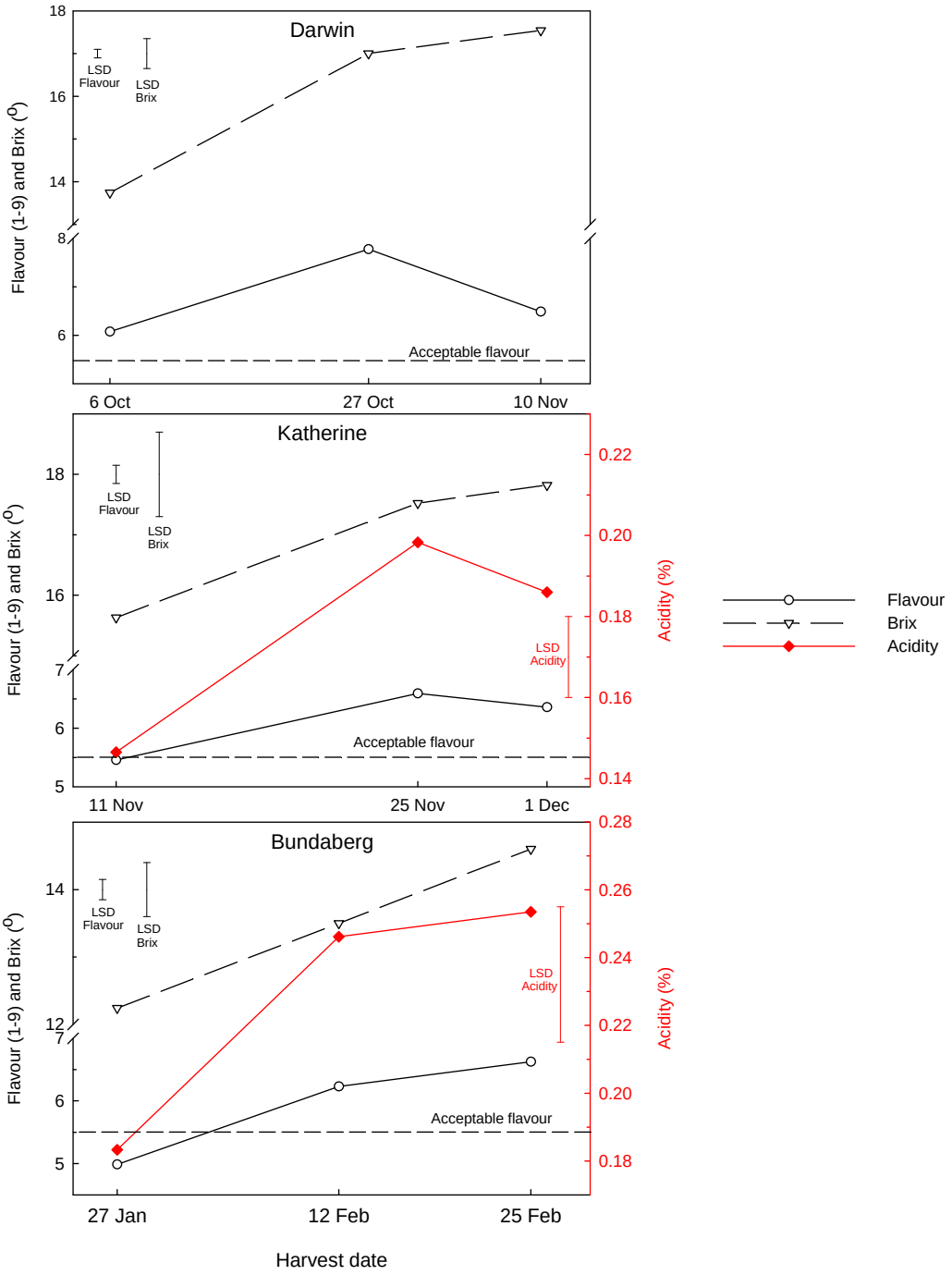


Figure 2 The effect of harvest date on flavour, ºBrix and acidity of Calypso™ mango grown at Darwin, Katherine and Bundaberg. Flavour was rated on a scale of one = dislike extremely, to 9 = like extremely. A rating of 5.5 indicates just acceptable flavour. Treatment means have to be greater than the vertical bar (LSD) to be statistically significantly different at 95% probability. There was no significant difference in acidity (%) for Darwin.

Plate 4 Skin damage observed in Darwin fruit that were loose packed into Mod6 trays with plastic liners and road freight to Nambour. The damage was most likely caused by rubbing on adjacent surfaces, and bruising on the sharper images of the wrinkles of the plastic liner.

4.2.4.4. Conclusions and recommendations

In Katherine, fruit drop increased significantly by two weeks after the start of commercial harvest, and one week later had reached almost 50% fruit drop. In Bundaberg, there was little fruit drop after two weeks, but about 30% fruit drop after four weeks. There was also significant fruit drop after two weeks at Darwin.

The percentage of harvested fruit in grade one decreased significantly to less than 50% by three weeks (Katherine) and four weeks (Bundaberg) after the start of commercial harvest, mainly because of fruit colouring on the tree.

At all sites, %DM increased to the second harvest (two weeks), but changed little to the third harvest (1-2 weeks) for Darwin and Katherine. In Bundaberg, %DM increased continually over the four weeks. At all sites, flesh colour increased fairly consistently with harvest.

NIRS accurately predicted %DM and flesh colour at early harvest but tended to slightly underestimate these parameters at later harvests.

Flavour increased from the first to the second harvest in Darwin and Katherine, but changed little at third harvest. ºBrix increased with harvest. Flavour, Brix and acidity increased with harvest at Bundaberg.

Lenticel spotting severity increased with later harvests in two of the three sites. Rots severity was very low in Darwin and Katherine, but increased with later harvests in Bundaberg.

For this season, the significant fruit drop with later harvests suggests that the harvest window for Darwin and Katherine was about two weeks, and for Bundaberg, about three weeks. The absence of any increase in flavour with later harvests indicates there was no benefit to leaving fruit longer on the tree.

Further work is required to confirm these results. It is likely that season will affect the length of the harvest window. However, commercial infrastructure requirements and operations need to be planned around the shortest harvest window, unless the length of the window can be predicted well before harvest to allow adjustments in harvesting/handling strategy.

5. Maximising eating quality

5.1. Maturity standards

5.1.1. Final verification of the maturity standards

5.1.1.1. Introduction

Research in the previous project (phase 1) suggested that a Calypso picking Guide colour of 7, heat units of 1640 and a minimum dry matter of about 14% would ensure acceptable eating quality of Calypso mango. The results also indicated little variation between regions.

These recommended standards were again evaluated for the three regions in the 2006/7 season. The major reasons for repeating this work was to address potential seasonal and regional variations, and to incorporate near infrared spectroscopy (NIRS) as a potential maturity indicator.

Calypso mango trees were tagged at full flowering, or individual panicles tagged because of the staggered flowering within each tree. Fruit from selected trees were harvested at weekly intervals over six weeks. The dry matter, flesh colour and Brix were recorded at harvest, and related to the flavour of the ripe fruit. The accumulated heat units (based on the number of degree days above 10°C, from full flowering to harvest) were also recorded.

Technical difficulties with the hand-held NIRS unit prevented inclusion of these data in this study. Additional trials on NIRS are presented in a separate report.

5.1.1.2. Materials and methods

5.1.1.2.1. Trees and fruit harvest

Similar methods were used in North Queensland and southeast Queensland, and a simpler protocol used in the Northern Territory. Trial locations and flowering dates are reported in Table 14.

Table 14. Details of the maturity experiments conducted on Calypso^{TM} mango in the three major growing regions.

	Northern Territory	North Queensland	Southeast Queensland
Location	Acacia Farms	Blushing Acres???	Oolloo Farms, Bundaberg
Flowering dates		17th July-14th August	11th August-27th September
Harvest dates	6th September-9th October	6th Nov-18th Dec	3rd January-14th February

In North Queensland and southeast Queensland, about 10 trees were tagged at flowering every week for about 6-8 weeks. The date of full flowering for each of these trees was recorded. From about four weeks before expected commercial harvest, 40-60 fruit were harvested from each of 3-6 trees that had flowered at different times. This provided a matrix of flowering and harvest dates to provide fruit of different maturity. The flowering and harvesting schedules are presented in Table 15.

Table 15 The days from full flowering to harvest, for each of the flowering and harvest dates in the North Queensland and southeast Queensland maturity trials.

North Queensland

Flowering date	Harvest date						
	6-Nov	13-Nov	20-Nov	27-Nov	4-Dec	11-Dec	18-Dec
17-Jul			126	133	140	147	154
24-Jul		112	119	126	133	140	147
31-Jul	98	105	112	119	126	133	140
7-Aug	91	98	105	112	119	126	
14-Aug	84	91	98	105	112		

South east Queensland

Flowering date	Harvest date						
	3-Jan	9-Jan	16-Jan	23-Jan	30-Jan	6-Feb	13-Feb
11-Aug			101	108	115	122	129
29-Aug		76	83	90	97	104	111
5-Sep	62	69	76	83	90	97	104
13-Sep	54	61	68	75	82	89	
20-Sep	47	54	61	68	75		
27-Sep	40	47	54	61	68		

For North Queensland, about 20-30 fruit per flowering date were assessed for maturity indicators at the DPI&F laboratories at Cairns, and the remaining 20-30 fruit airfreighted to the DPI&F laboratories at Maroochy Research Station (MRS) within one day of harvest for eating quality assessment. For southeast Queensland, all fruit were assessed at MRS.

In the Northern Territory, about 15 trees were tagged at full flowering on the same day. About 40-60 fruit were harvested every week for about six weeks. The fruit were transported to the DPI&F postharvest laboratories at Berrimah, where maturity indicators and eating quality were assessed.

About 20-30 fruit per flowering time were used to determine dry matter, flesh colour and Brix. The remaining 20-30 fruit were treated with 10 ppm ethylene for 2 days at 20°C, then ripened at 20°C.

5.1.1.2.2. Dry matter, Brix and flesh colour at harvest, and heat units

One cheek from each of the fruit per flowering time was removed and the flesh colour about midway between the skin and the seed was rated using the Calypso Picking Guide. Flesh colour halfway between the skin and seed was also measured with a Minolta Chromameter. Longitudinal sections of each cheek were removed, peeled and the cheeks from 7-10 fruit combined and blended in a food processor. This provided three replications of 7-10 fruit each for each flowering date at each harvest. A sub-sample of the blended flesh was dried at 65°C for about two days until no further water was lost, and the dry matter calculated.

A sample of juice was taken from the fruit after blending, the juice filtered, and the Brix determined using an Atago bench refractometer.

A temperature logger in a Stevenson screen was placed near the orchard to determine heat units accumulated from full flowering to fruit harvest (temperatures recorded every hour). The date of full flowering was determined as the date when at least 50% of the panicles on the tree had reached 50% flowering (that is, about 50% of the flowers on each panicle had opened; Plate 5). The accumulated heat units were calculated as the number of days per degree above 10°C.

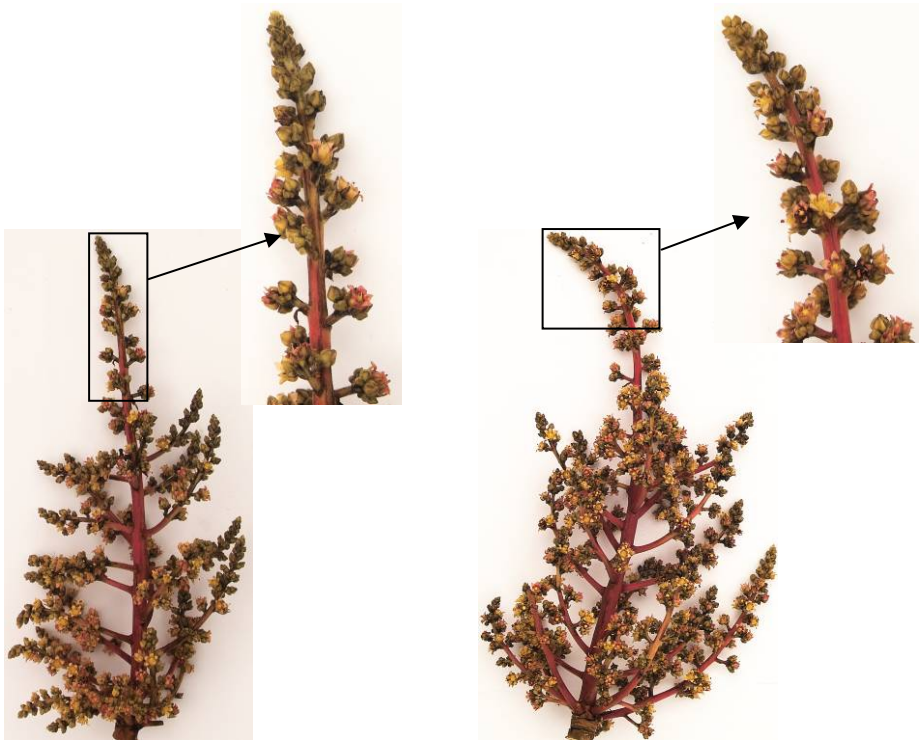


Plate 5 Details of tagged panicles (those that had reached 50% flowering) from Calypso™ trees.

5.1.1.2.3. Ripe fruit quality

The flavour, Brix and acidity of the flesh were determined 3-4 days (early maturity) or 2-3 days (late maturity) after the fruit had reached full colour (no green colour remaining on the skin). Previous results indicated that the fruit had reached full flavour by this stage.

At each harvest, the flesh from 7-10 fruit per flowering time was removed, mixed, and given to the tasters for flavour assessment. This was repeated twice with the remaining fruit per flowering date, which provided replications for the flavour assessments. Brix and acidity for these samples were replicated in a similar way (three sub-samples per flowering time for each harvest). Titratable acidity was determined using a Metrohm Titrino autotitrater and the results expressed as % citric acid. Brix was measured using a Atago refractometer with temperature compensation.

Fruit samples were given to about 16 staff at MRS. They were asked to rate the samples for flavour based on the following question: "How do you like the sample as a fruit. That is, do not compare it to other mangoes you have tasted, but how do you like it as a fruit itself"?

The following rating scale was used:

1=dislike extremely
2=dislike a lot
3=dislike somewhat
4=dislike slightly
5=neither like nor dislike
6=like slightly
7=like somewhat
8=like a lot
9=like extremely.

A rating of at least 5.5 was considered to indicate an acceptable eating quality.

Previous comparisons between tasters from the research station, and a larger random population from Brisbane, indicated little difference in assessment between the two groups.

5.1.1.3. Results

5.1.1.3.1. Northern Territory

Flavour

Generally the flavour increased with later harvests (Figure 3). Flavour was very low in the early harvests and only reached the acceptable level of 5.5 on about 2nd October.

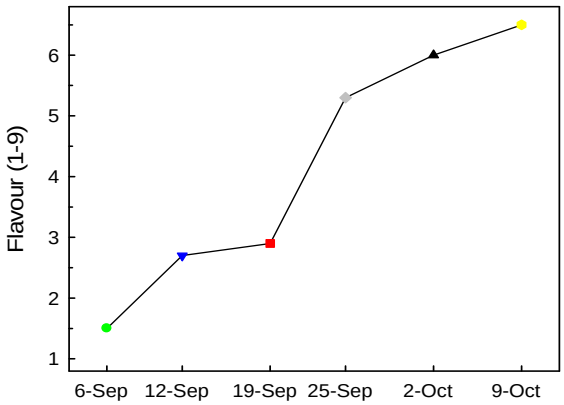


Figure 3. Northern Territory. The rating of flavour of ripe Calypso™ mangoes harvested from 6th September to 9th October. Fruit were considered to have an acceptable flavour at a rating of 5.5.

Dry matter, Brix and colour of the flesh at harvest

The dry matter, flesh colour and Brix of the flesh at harvest generally increased with later harvests (see Figure 4 and Figure 5).

Relation between flavour and maturity indicators

Figure 6 shows the relation between flavour and dry matter, flesh colour, Brix and heat units. The small sample number and the variation between these samples resulted in a less reliable estimate of minimum maturity standards.

The dry matter, Brix, flesh colour and heat units that relate to a flavour rating of 5.5 were:

- 13.8 % dry matter
- a flesh colour of 6 using the Calypso Picking Guide
- 7.0° Brix
- 1650 for heat units

Flesh colour followed by heat units and dry matter had the strongest relationship with flavour (indicated by the higher r^2 value). As in the previous season, Brix was a less reliable indicator of flavour than the other measures.

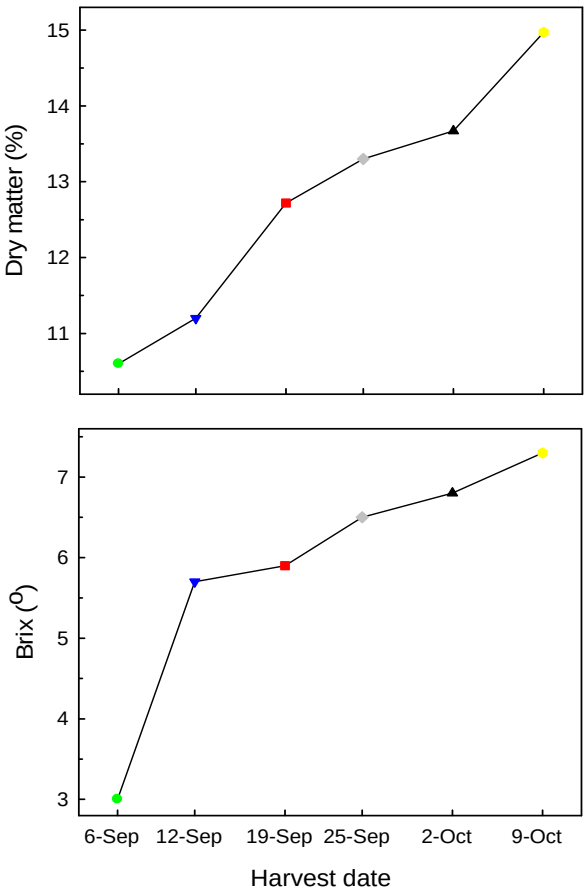


Figure 4. Northern Territory. The dry matter, (using the Calypso™ mango picking guide) and Brix at harvest of Calypso™ mangoes harvested from 6th September to 9th October.

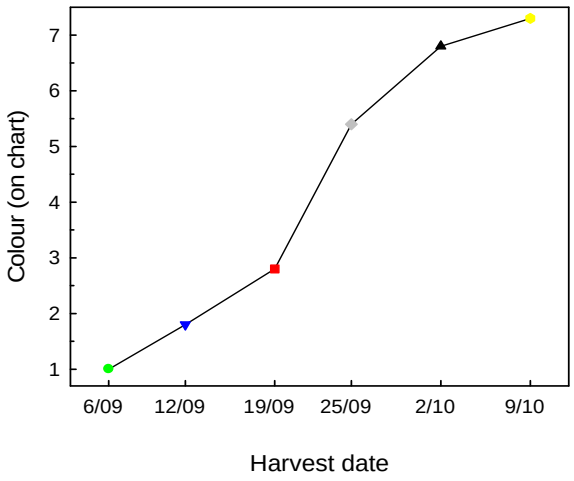


Figure 5. Northern Territory. The flesh colour at harvest of Calypso™ mangoes harvested from 6th September to 9th October.

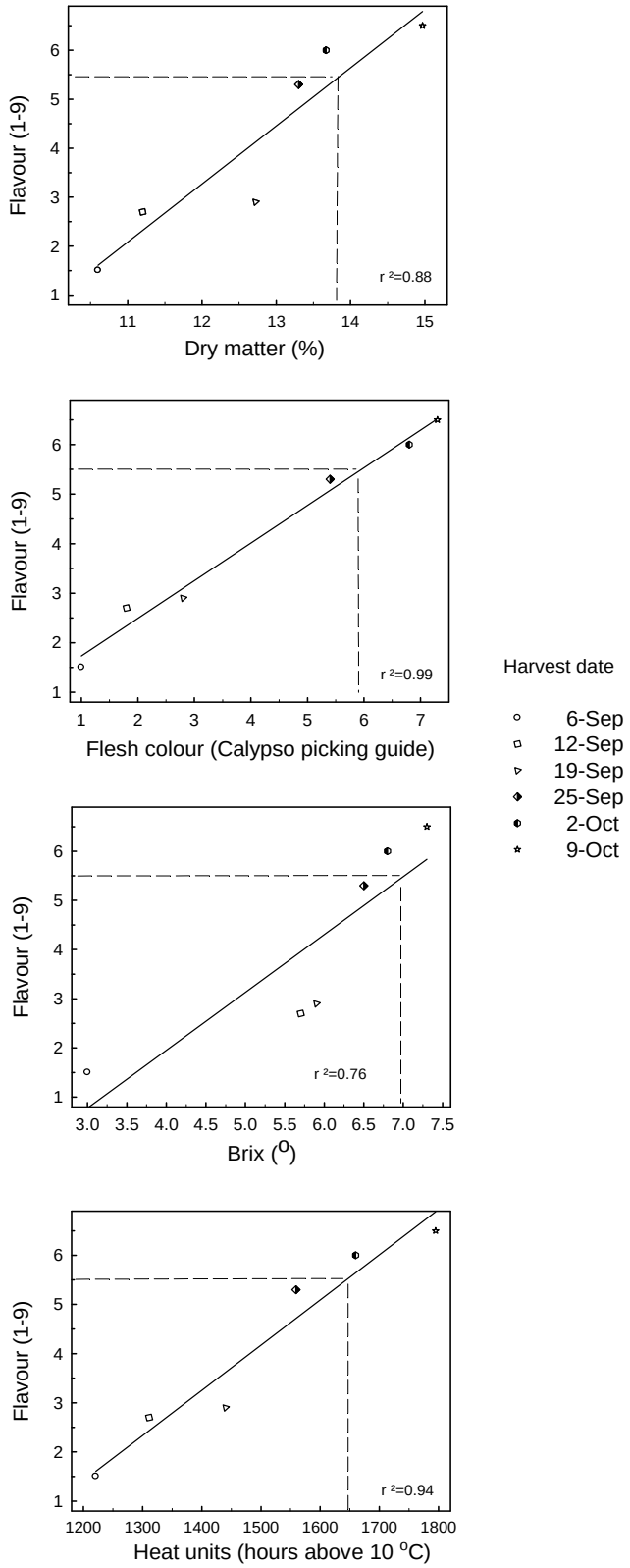


Figure 6. Northern Territory. The relationship between flesh dry matter, colour or Brix at harvest, and heat units, with flavour of ripe Calypso™ mangoes. Each point represents a different sample of 10 fruit within each harvest date.

5.1.1.3.2. Nth Queensland

Flavour

Flavour generally improved with later harvests (see Figure 7). There was little consistent difference in flavour between different flowering dates when harvested at the same time, except perhaps for the 7th August flowering date having consistently lower flavour during the early harvests.

For most flowering dates, fruit generally reached acceptable flavour (5.5) by about 4th December.

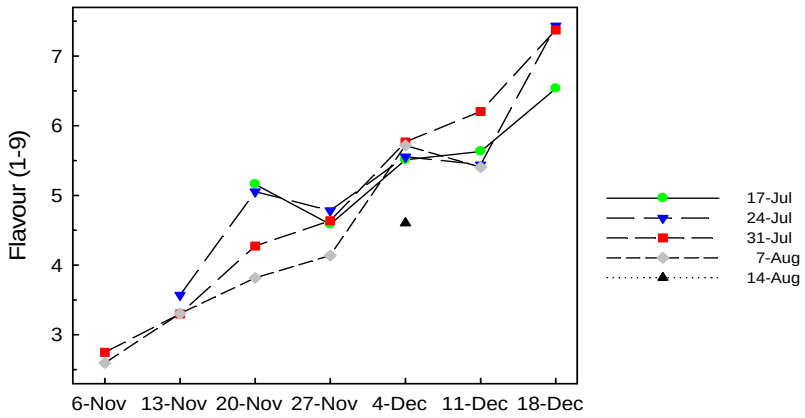


Figure 7. North Queensland. The flavour of ripe Calypso™ mangoes harvested from 6th November to 18th December. Fruit were considered to have an acceptable flavour at a rating of 5.5.

Brix and acidity of the ripe flesh

Brix increased fairly consistently with each harvest (see Figure 8). Fruit from the later flowerings often had less Brix than those from earlier flowerings, but this was not consistent.

Flesh acidity decreased during the first three harvests, then increased until the second last harvest before decreasing at the last harvest (Figure 8). The reasons for this pattern is not known. There was little effect of flowering date on flesh acidity.

Brix of the ripe flesh had a very strong and significant influence on flavour (Figure 9). At the acceptable flavour rating of 5.5, the Brix level was 11.6°.

There was no relationship between acidity and flavour (Figure 9).

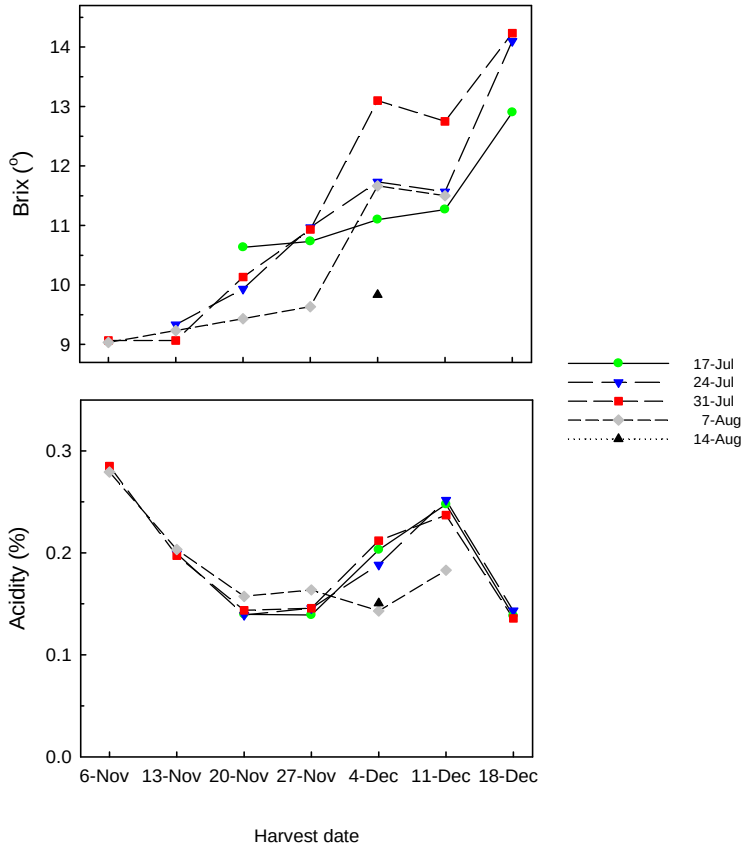


Figure 8. North Queensland. The Brix and acidity of the flesh of ripe Calypso^{TM} mangoes harvested from 6th November to 18th December.

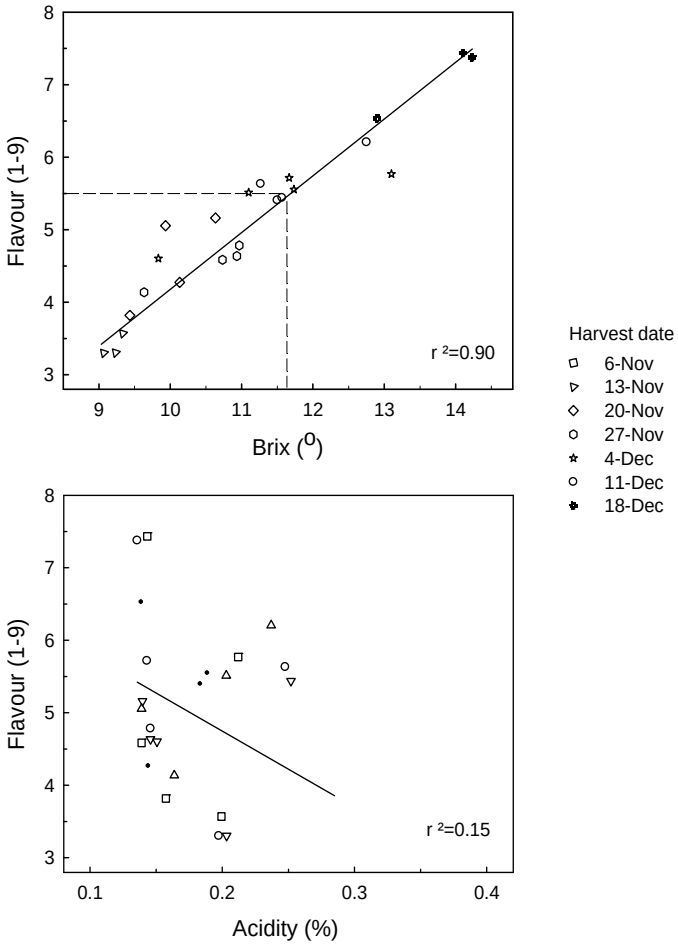


Figure 9. North Queensland. The relationship between ripe flesh Brix or acidity with the flavour of ripe Calypso™ mangoes harvested from 6th November to 18th December. Each point represents a sample of 10 fruit within each harvest date.

Relation between flavour and maturity indicators

Figure 12 shows the relation between flavour and dry matter, flesh colour and Brix in fruit from both farms and a number of flowering times and harvests.

The dry matter, Brix and flesh colour that relate to an acceptable flavour (rating of 5.5) were:

- 13.3 % dry matter
- 6.2 for colour using the 'Calypso' picking guide
- 7.9° Brix
- 1385 heat units

Flesh colour, followed by dry matter and heat units had the strongest relationships with flavour, as indicated by the higher r^2 values, while Brix had a weaker relationship.

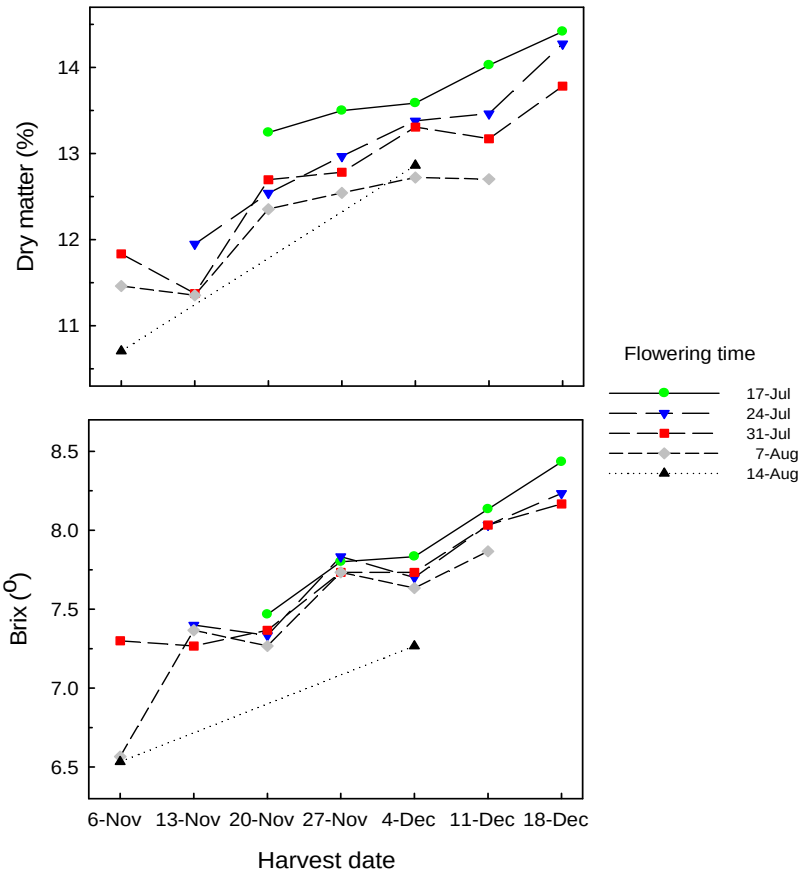


Figure 10. North Queensland. The dry matter and Brix at harvest of Calypso™ mangoes harvested from 6th November to 18th December.

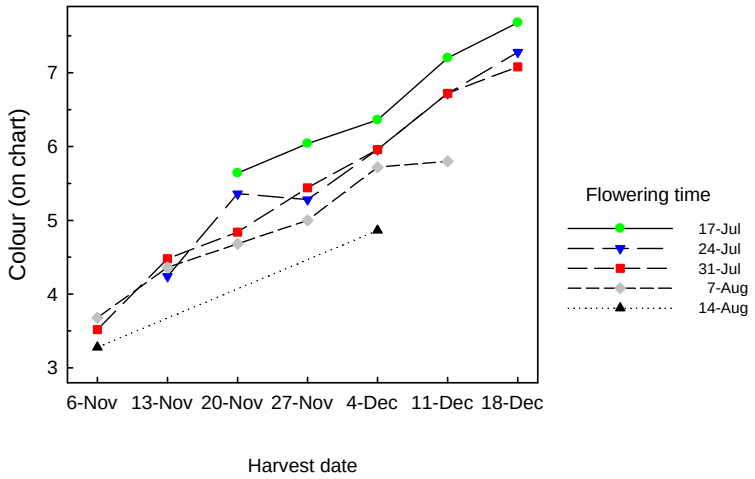


Figure 11. North Queensland. The flesh colour (using the Calypso™ mango picking guide) at harvest of Calypso mangoes harvested from 6th November to 18th December.

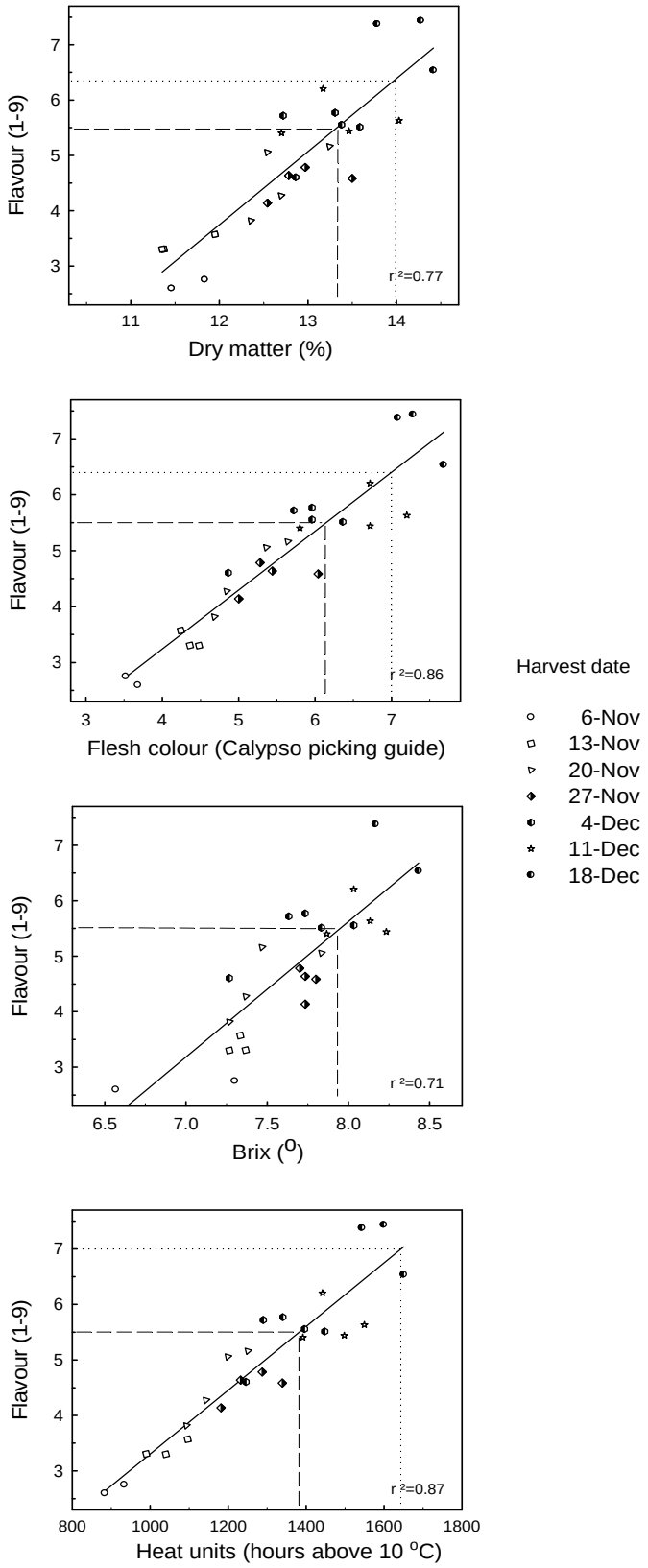


Figure 12. North Queensland. The relationship between flesh dry matter, colour or Brix at harvest, and heat units, with flavour of ripe Calypso™ mangoes. Each point represents a different sample of 20-30 fruit within each farm and harvest date.

5.1.1.3.3. Southeast Queensland

Flavour

The flavour increased with the first 3-4 harvests (Figure 13) but did not change much after 23rd January. Fruit from the latest flowering trees often had the lowest flavour, but there was little difference between the other flowering dates. Acceptable flavour was achieved by about 16th January.

Fruit from the latest flowering generally had the lowest flavour, but there was little consistent difference in flavour between the other flowering dates.

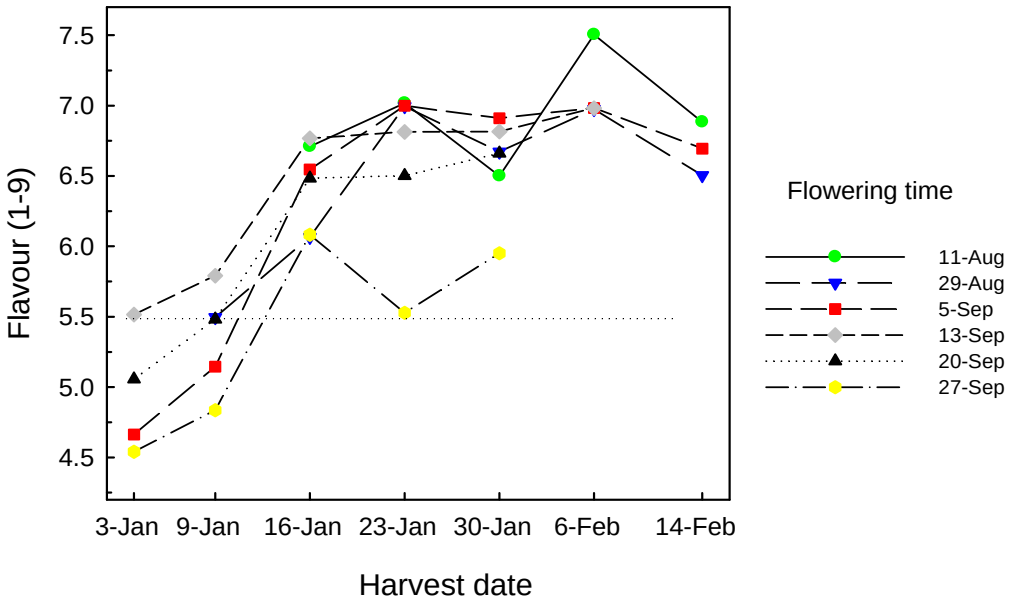


Figure 13. Southeast Queensland. The rating of flavour of ripe Calypso™ mangoes harvested from 3rd January to 14th February. The fruit were from trees that had reached full flowering between 11th August and 27th September. Fruit were considered to have an acceptable flavour at a rating of 5.5.

Acidity and Brix of the ripe flesh

The Brix in the ripe fresh also increased over the first five harvests, but after that there was little change in Brix (see Figure 14). This followed a somewhat similar pattern to flavour, except the flavour reached a maximum after 3-4 harvests.

Fruit from the latest flowering had the lowest Brix, but there was little consistent difference for the other flowering dates (Figure 14).

Acidity also increased with later harvests but the increases were less consistent. There was little consistent effect of flowering date on flesh acidity, although occasionally fruit from the earliest flowering had higher flesh acidity than those from later flowering.

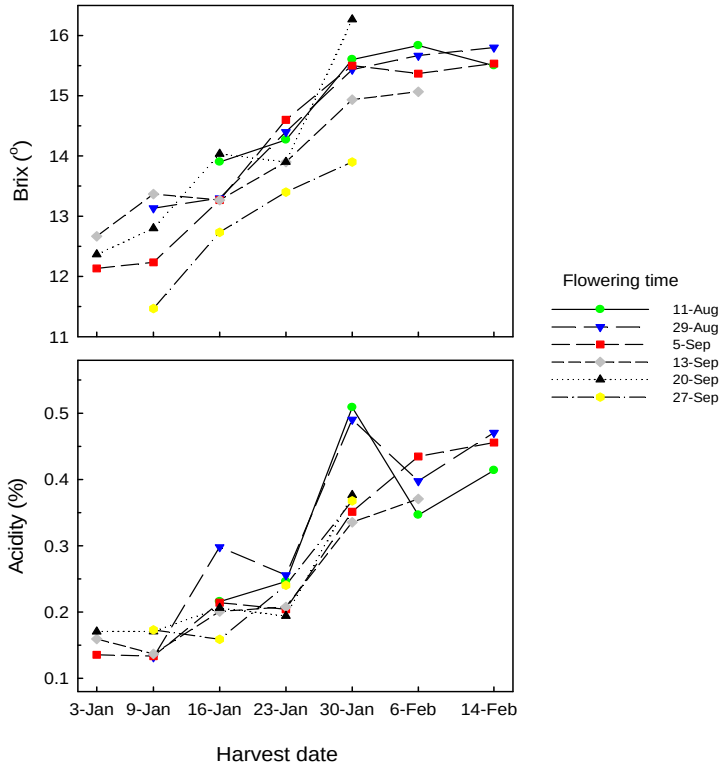


Figure 14. Southeast Queensland. The Brix and acidity of the flesh of ripe Calypso™ mangoes harvested from 3rd January to 14th February. The fruit were from panicles that had reached full flowering between 11th August and 27th September.

Figure 15 again shows a strong relationship between Brix in the ripe flesh, and flavour. Above about 14° Brix, there was little increase in flavour, suggesting that Brix was not the only determinant of flavour. This pattern has not been observed in previous years. Fruit with a flavour rating of 5.5 had about 12.1% and Brix.

The relationship between acidity and flavour was weak, suggesting that acidity played only a small role in flavour.

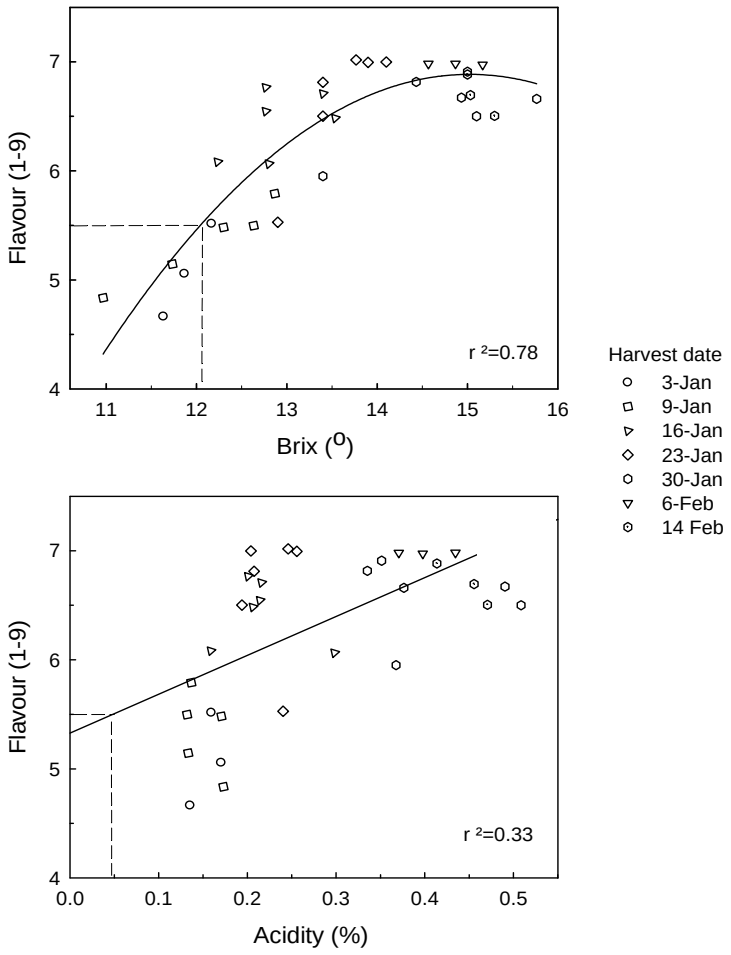


Figure 15. Southeast Queensland. The relationship between ripe flesh Brix or acidity with the flavour of ripe Calypso™ mangoes. Each point represents a different sample of 20-30 fruit within each flowering time and harvest date.

Dry matter, flesh colour and Brix of the flesh at harvest

Dry matter ranged from 13-14% at the first harvest, and generally increased with later harvests to about 16-17% at the final harvest (Figure 16).

The Brix in the just harvested fruit started at about 7.0-7.6° and increased with later harvests. Brix did not increase consistently after about 30th January.

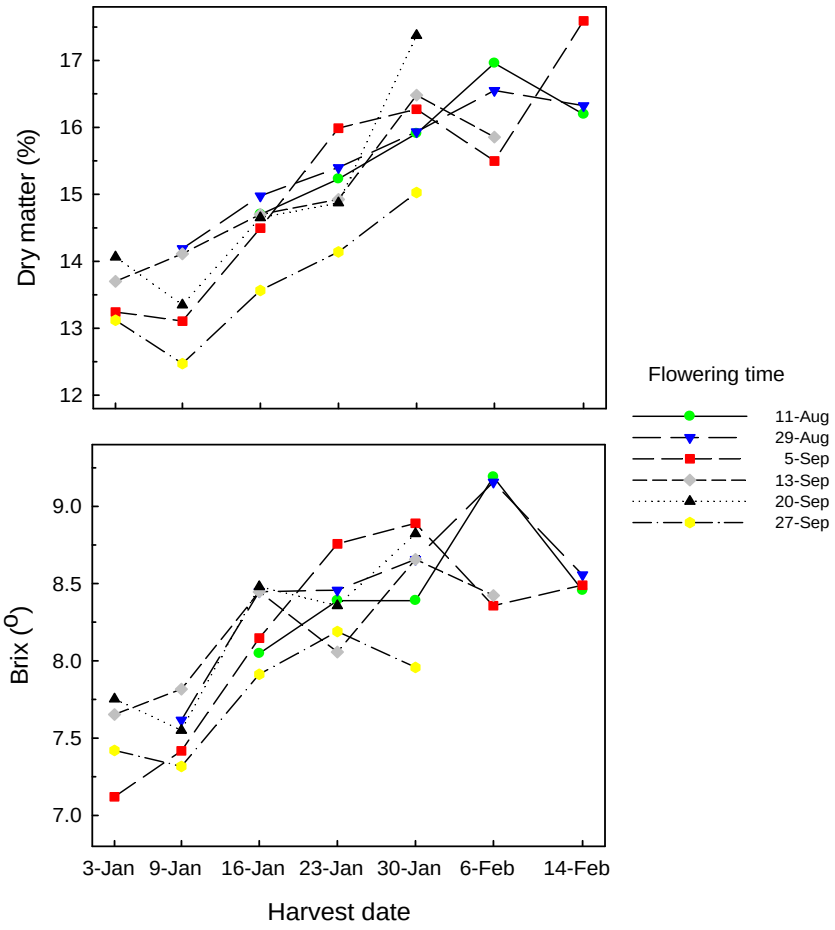


Figure 16. Southeast Queensland. The dry matter and Brix at harvest of Calypso™ mangoes harvested from 3rd January to 14th February. The fruit were from panicles that had reached full flowering between 11th August and 27th September.

Flesh colour

The flesh colour ratings increased with later harvests (Figure 17). Fruit from the latest flowering had the least yellow flesh colour at all harvests, and the flesh was usually less yellow with later flowerings when harvested at the same time. The hue angle of the flesh (lower values indicate more yellow flesh) confirmed the results obtained with the Calypso Picking Guide.

Relation between flavour and maturity indicators

Figure 18 shows the relation between flavour and dry matter, flesh colour, Brix and heat units. The relationship of dry matter and Brix with flavour was linear, but the relationship with flesh colour and heat units was not. Non-linear relationships have not been observed in previous seasons. These may be related to the fact that flavour did not increase above about seven, even though Brix in the ripe flesh continued to increase to about 16°.

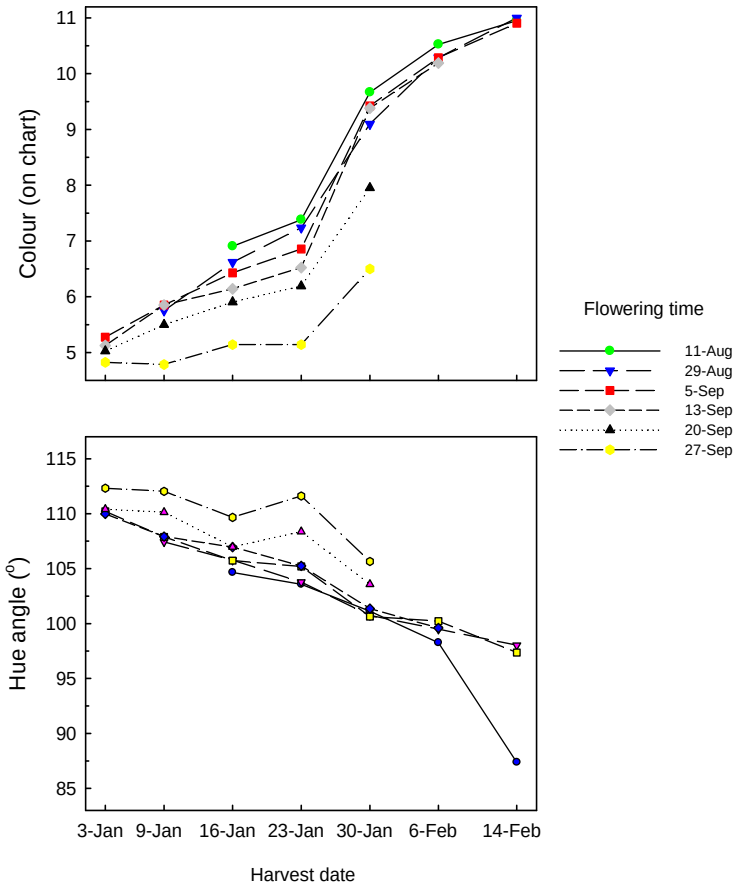


Figure 17. Southeast Queensland. The flesh colour of Calypso^{TM} mango fruit at harvest, measured with the Calypso Picking Guide, and the hue angle (lower values indicate more yellow colour). The fruit were harvested from 3rd January to 14th February. The fruit were from panicles that had reached full flowering between 11th August and 27th September.

The dry matter, Brix, flesh colour and heat units that relate to an acceptable flavour (rating of 5.5) were:

- 13.5 % dry matter
- 5.6 for colour using the Calypso Picking Guide
- 7.7 Brix
- 1300 for heat units

The recommended dry matter at acceptable flavour was similar to previous years, however the results for flesh colour and heat units was lower. The lower results may be related to the non-linear nature of the relationship to flavour.

Using the previous project recommendations of 14% dry matter, seven flesh colour and 1640 heat units, the flavour was 5.7, 6.7, and 6.7, respectively. Using the recommendations from previous seasons would have resulted in fruit of better flavour to previous years, which is a significant commercial benefit.

Heat units, Brix and flesh colour had the strongest relationship with flavour (indicated by the higher r^2 value).

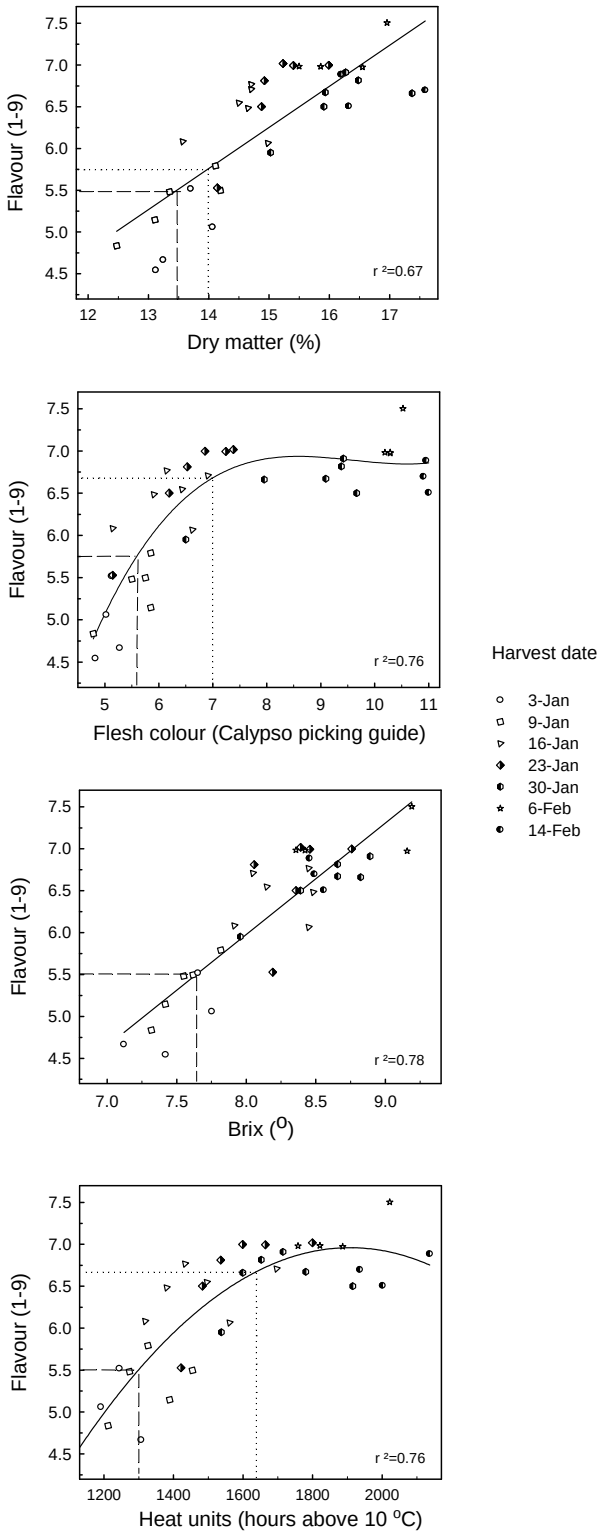


Figure 18. Southeast Queensland. The relationship between flesh dry matter, colour or Brix at harvest, and heat units, with flavour of ripe Calypso™ mangoes. Each point represents a different sample of 20-30 fruit within each flowering time and harvest date.

5.1.2. Non-destructive maturity assessment with NIRS

5.1.2.1. Introduction

Near infrared spectroscopy (NIRS) is used successfully for rapid, non-destructive assessment of plant constituents (Clark *et al.* 2003; Lammertyn *et al.* 2001). In 'Kensington Pride', it can be used to predict DM in just-harvested fruit (Guthrie and Walsh 1997), Brix in ripe fruit, and Brix of ripened fruit from spectra collected at the just harvested stage (Subedi *et al*., 2007). Thus this technology offers the potential for in-line assessment of harvested fruit maturity, and also as an infield maturity indicator of fruit on the tree. A preliminary investigation was conducted in 2005/6 in southeast Queensland to evaluate its effectiveness in predicting, at harvest, DM and flesh colour, and ripe flavour and Brix. These results indicated that NIRS on just harvested fruit could separate fruit into different flavour categories based on predicted dry matter. Also, there was a high correlation between predicted dry matter at harvest, and Brix in the ripe flesh. On this basis, research was conducted this season to confirm the potential for non-destructive maturity testing of fruit on the tree, with a view to determining the start of commercial harvest and assist in select harvesting the more mature fruit.

The previous seasons work was done using the portable laboratory-based NIRS unit connected to a laptop computer (called the "shoebox"). In the current work, a portable handgun was tested, which contained the same instrumentation as the shoebox, but with inbuilt software.

The following questions were considered:

1) Can the handgun assist the grower to identify when to start harvest of a block based on the current minimum maturity standards?
   a) Can NIRS accurately predict flesh colour and dry matter at harvest?
   b) Can NIRS accurately predict Brix and flavour in the ripe fruit from spectra taken at harvest?
   c) What assessment routine is required to adequately sample an orchard?
   d) Is accuracy of the handgun compromised in the field by ambient light or temperature?
2) Can the handgun assist the grower identify patterns of variation in fruit maturity within the tree and across the block so that sound instructions can be given to pickers to ensure the most mature fruit are harvested first.
   a) What assessment routine is required to adequately sample a fruit (i.e. what variation in DM and internal colour exists within a fruit?) Does NIRS need to be used on one or two cheeks of a fruit?
   b) What assessment routine is required to adequately sample a tree? (what is the variation in DM and colour throughout a tree?)
3) How accurate are the current instructions given to picking teams in order to harvest the most mature fruit first?
4) Can NIRS be used as an effective sorting system in the packhouse to increase the uniformity of fruit ripening and quality?

Trials were conducted in the Northern Territory, North Queensland in southeast Queensland to answer some of these questions. Mechanical difficulties compromised some of the experimental plans, but sufficient results were obtained to indicate potential benefits and the need for future work.

Previous seasons experience in south east Queensland suggested it was difficult to estimate fruit maturity based on external characteristics, because there was little change in external appearance during the last 3-4 weeks before minimum maturity. However, grower feedback suggested that this may not be the case in other growing areas. Therefore, the possibility of

estimating maturity based on external fruit characteristics (colour, shape etc) was evaluated, and observations made on whether pickers under typical commercial conditions could use these guidelines to selectively harvest the more mature fruit at the start of the season.

5.1.2.2. Materials and methods

Some of the above questions were studied as follows

Can NIRS accurately predict flesh colour and dry matter at harvest?

This was evaluated with fruit from Darwin and Bundaberg. An evaluation with North Queensland fruit was not possible because of mechanical difficulties with a handgun.

About 100-450 Calypso^{TM} fruit were harvested randomly on different days within a two week period. The fruit were obtained from full sun, full shade, and from inside, outside and from around the canopy. In a cool, shaded area of the packhouse, the NIRS spectra was taken on both sides of the fruit (two spectra per fruit). A 25 mm core of skin and flesh was taken at the point of the NIRS measurement, the skin removed and the Hunter b value (using the Minolta colour meter), and the Calypso Picking Guide flesh colour score was measured at approximately 10 mm in from the skin. The top 10 mm of the plug (representing a core of flesh from just under the skin to 10 mm depth) was cut in two, placed in a pre-weighed paper cup, weighed, then dried at 65°C for at least two days using a domestic dehydrator. The dry sample was re-weighed and the % dry matter determined.

In some instances, readings were also taken with the "shoebox" unit.

Can NIRS accurately predict Brix and flavour in the ripe fruit from spectra taken at harvest?

NIRS spectra were to be taken of fruit used in the maturity trials in northern Queensland and South East Queensland. The same fruit were then to be ripened, and assessed for ripe fruit Brix and flavour. However, mechanical difficulties with the handgun prevented accurate results being obtained.

As an alternative, 160 fruit (100 for model development, and 60 for verification) were harvested from a Bundaberg orchard. Spectra were obtained on the just-harvested fruit, the fruit ripened at 20°C, then spectra taken on the ripe fruit and the flesh Brix determined.

What assessment routine is required to accurately estimate individual fruit maturity, and the average maturity of a block.

In most trials, assessments were done on both sides of the fruit. These results are presented under other sections of this report.

Results from the above experiments were used to estimate that about 100 fruit would need to be assessed to provide acceptable accuracy in predicting maturity based on dry matter.

Is accuracy of the handgun compromised in the field by ambient light or temperature?

As a preliminary trial in the Northern Territory, spectra were recorded 20 times from the same area of a single fruit, under the following conditions:

- Both the fruit and the hand unit at room temperature (about 23°C), and the readings taken in the shade
- Fruit were assessed inside in an airconditioned, low light environment,
- The same fruit assessed outside in the shade
- The same fruit assessed in full sun
- The readings taken in the shade with the fruit at room temperature (about 23°C), but the handgun temperature increased to 40°C by placing in an oven.

The mean and standard deviation of the readings was determined.

Can the handgun assist the grower identify patterns of variation in fruit maturity within the tree and across the block so that sound instructions can be given to pickers to ensure the most mature fruit are harvested first.
This was not adequately tested this season.

What assessment routine is required to adequately sample a tree? (what is the variation in DM and colour throughout a tree?)
This was not adequately tested this season.

How accurate are the current instructions given to picking teams in order to harvest the most mature fruit first?
During the early, select pick in the Northern Territory and North Queensland, spectra were obtained of fruit from the field bin that had been selectively picked by the commercial picking teams as being more mature. Spectra were also obtained from fruit on the trees that had just been picked (those sampled from the field bins). The average estimated and actual flesh colour (based on the Calypso Picking Guide), and the error in estimation, was determined.

Can NIRS be used as an effective sorting system in the packhouse to increase the uniformity of fruit ripening and quality?
No specific work was done on this aspect. However, results from the above trials provided some indication of suitability for packhouse sorting.

5.1.2.2.1. Statistical analysis

Partial least squares (PLS) calibration models were developed to relate spectra to reference values, with these models then loaded to the shoebox or handheld units to allow real time prediction of dry matter or flesh colour in fruit. The chemometric package 'The Unscrambler' (Camo Scientific) was used in this work. Model performance was assessed in terms of cross validation (models assessed on a group of samples from a given population, with these samples not used in the calibration), and in terms of prediction of an entirely different population.

5.1.2.3. Results

5.1.2.3.1. General

The 'fitness' of a calibration model is seen in a plot of predicted vs. actual values. There are are number of statistical terms that can be used to describe this 'fitness':

- R (correlation coefficient) or R^2 (coefficient of determination). A value of 1.0 is perfect! An R^2 of >0.75 is required to sort a population into two graoups (for example, low and high dry matter).
- RMSEP or RMSECV (root of the mean of the square of the residuals between predicted and actual values for prediction of an independent set, RMSEP, or in cross validation of one set, RMSECV). These are a measure of the error of the prediction. For example, a RMSEP of 2.1% DM will not allow accurate separation of fruit that are less than 2.1% different in dry matter.
- If a typical population standard deviation (SD) on DM in mango fruit is 3 %DM, then it would be practically useful to have a method with a RMSEP of at least as low as 1.5%. For example, if the SD on Hunter b of mango flesh is 5, then an RMSEP of less than 2.5 is desired.
- SDR is a useful term to relate SD and RMSECV/P, with SDR = SD/ RMSECV/P

In addition, a model is built using a number of 'principle components' (PCs) or 'factors'. The number of factors used in building a model should be reported. It is very easy to 'over-fit' data by using a high number of factors (typically more than 12). Such models 'look good' and can have high R and low RMSECV values, however, when used in prediction of an

independent set, such models may fail spectacularly. A typical number of factors for a relatively complex sample like fruit is 7 to 12.

5.1.2.3.2. Can NIRS accurately predict flesh colour and dry matter at harvest?

Darwin: The best model relating NIRS spectra and flesh dry matter was obtained using the near infrared wavelengths of 760-960 nm, which was similar to 'Kensington Pride'. This provided an acceptable correlation of 0.87, with a SDR of 2.1 (Table 16).

The best correlations for Hunter b and flesh colour (based on the Calypso Picking Guide) were obtained using wavelength 500-1040 nm. The model was based primarily on absorbance in the visible wavelengths (500-700 nm), but was marginally improved by inclusion of the NIR region. The model for flesh colour – picking guide was not quite as accurate as that for dry matter (e.g. SDR 1.9 compared with 2.1), while that for flesh colour – Hunter b by colorimeter, was similar to that for dry matter (SDR 2.1) (Table 16).

Table 16. Darwin region; calibration using the handgun unit 04. Summary of model characteristics for using near infrared spectroscopy for predicting flesh dry matter and flesh colour (based on the Hunter b value) for Calypso^{TM} mango. Two separate fruit populations were used. SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV .

Attributes	Range(nm)	No. of spectra	Mean	SD	Outliers	PCs	R	RMSECV	SDR
DM	760-960	540	16.1	1.49	2	10	0.87	0.72	2.07
Picking guide	500-1040	540	6.5	2.52	10	8	0.84	1.36	1.85
Hunter b	500-1040	540	24.2	5.06	15	8	0.88	2.38	2.13
Picking guide	500-1040	843	6.29	2.31	37	8	0.84	1.26	1.83
Hunter b	500-1040	843	23.9	4.6	21	10	0.86	2.33	1.97

A different population of fruit were tested with the Shoebox (Table 17). This unit had been used the previous season for prediction of dry matter and Brix in 'Kensington Pride' mango. A wavelength range of 726 – 919 nm had been selected as optimal for this work. This range was used without further optimisation for both dry matter and flesh colour (Hunter b) in the current study.

Table 17. Darwin region; calibration using the Shoebox unit. Summary of model characteristics for using near infrared spectroscopy for predicting flesh dry matter and flesh colour (based on the Hunter b value) for Calypso^{TM} mango. Different fruit than Table 16 were used. SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

Attributes	Range(nm)	No. of spectra	Mean	SD	Outliers	PCs	R	RMSECV	SDR
DM	726-919	60	16.6	2.6	0	7	0.99	0.34	7.65
Hunter b	726-919	60	24.1	4.91	0	7	0.9	2.14	2.29

The 'shoebox' unit supported better models than with the handgun, as indicated by the higher R and SDR values (e.g. SDR of 7.7 on dry matter. A better model was obtained with dry matter than with flesh colour (Hunter b, SDR 2.3).

The handgun was returned to the supplier for servicing to try to improve its performance for the Bundaberg season.

Bundaberg: The 500-1040 nm range was established as the best range on the Darwin fruit. This range was initially used on the Bundaberg fruit, but later tests indicated that the restricted wavelength range of 730-920 supported better models for the Bundaberg fruit, with both the

handgun and the shoebox. This is very similar to the Darwin results but with a better correlation (higher R values).

For flesh colour however, the optimum wavelengths for the handgun was only in the near infrared range (730-930 nm) compared with the visible wavelengths for the Darwin fruit. The optimum wavelengths for the shoebox was similar for both the Darwin and Bundaberg fruit. The reason for the shift in optimum handgun wavelengths between Darwin and Bundaberg is uncertain, but may be related to some improvements to the handgun during servicing between the Darwin and Bundaberg seasons. If the near infrared range for predicting flesh colour proves to be consistent across seasons/locations, then this may provide a better model because of reduced interference from pigments in the skin.

As with Darwin, dry matter provided a better model with all populations and with both NIRS units, compared with flesh colour. The shoebox was also better than the handgun (Table 18).

In relation to prediction (Table 19), both the handgun and shoebox predicted dry matter very well (R=0.96 and 0.98 respectively). This result was obtained using different fruit from the Bundaberg farm for the calibration and for the prediction. The next step will be to use fruit from different production regions for calibration and prediction, which will test how well the same model can be used to fruit from different regions/farms.

Prediction of flesh colour was acceptable, but not good.

For all three parameters, the Shoebox was more accurate than the handgun, indicating further improvements to the handgun are possible.

5.1.2.3.3. Can NIRS accurately predict Brix and flavour in the ripe fruit from spectra taken at harvest?

Acceptable calibration models were obtained for predicting Brix in the ripe fruit using just-harvested fruit, or on ripe fruit (Table 20). Again, the shoebox performed better than the handgun. Also, NIRS of both green and ripe fruit was able to accurately predict Brix in the ripe fruit (R up to 0.93), with the shoebox again performing better than the handgun (Table 21).

Table 18. Bundaberg region; Calibration. Summary of model characteristics for using near infrared spectroscopy for predicting flesh dry matter and flesh colour (based on the Hunter b value and the Calypso Picking Guide) for Calypso™ mango. The NIRS spectra were obtained with the handgun unit 04 and the Shoebox unit. SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

Attributes	Range(nm)	Mean	SD	Outliers	PCs	R	RMSECV	SDR	Slope
Handgun 04									
Population A (100 spectra)									
DM	726-919	14.3	3.3	0	7	0.96	0.91	3.7	0.93
Picking guide	726-919	6.2	2.1	0	6	0.8	1.24	1.7	0.7
Hunter b	726-919	25.9	5.3	1	7	0.85	2.84	1.9	0.77
Population B (187 spectra)									
DM	726-919	17.7	1.56						
Picking guide	500-1040	8.51	2.68						
Hunter b	500-1040	37.18	8.83						
Populations A+B (287 spectra)									
DM	726-919	16.52	2.83						
Picking guide	500-1040	7.7	2.73						
Hunter b	500-1040	33.27	9.47						
Shoebox									
Population A (100 spectra)									
DM	726-919	14.32	3.31	1	4	0.98	0.59	5.610	0.97
Picking guide	500-1040	6.1	1.94	1	7	0.85	1	1.940	0.76
Hunter b	500-1040	25.91	5.3	1	7	0.85	2.75	1.927	0.76
Population B (187 spectra)									
DM	726-919	17.7	1.56	0	5	0.92	0.6	2.600	0.86
Picking guide	500-1040	8.51	2.68	15	3	0.76	1.71	1.567	0.59
Hunter b	500-1040	37.18	8.83	15	3	0.84	4.48	1.971	0.72
Populations A+B (287 spectra)									
DM	726-919	16.52	2.83	0	6	0.97	0.66	4.288	0.95
Picking guide	500-1040	7.7	2.73	6	4	0.80	1.6	1.706	0.66
Hunter b	500-1040	33.27	9.47	6	4	0.82	5.11	1.853	0.69

Table 19. Bundaberg region; prediction. Results from predicting flesh dry matter and flesh colour (based on the Hunter b value and the Calypso Picking Guide) of Calypso™ mango using near infrared spectroscopy (NIRS). The NIRS spectra were obtained with the handgun unit 04 and the Shoebox unit. SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

	Population used for											
Attributes	Calibration	Prediction	Range (nm)	Mean	SD	Outliers	PCs	R	RMSECV	SDR	Bias	Slope
iQ P04												
DM	B (356 spectra)	A (100)	726-919	14.3	3.33	0	8	0.96	1.42	2.345	0.98	0.78
Picking guide	B (356)	A (100)	726-919	6.2	2.07	0	5	0.80	1.29	1.605	0.19	0.79
Hunter b	B (356)	A (100)	726-919	25.9	5.3	0	8	0.85	4.85	1.093	-3.4	1.04
SHOEBOX												
DM	Subset of B (187)	A (100)	726-919	14.32	3.31	0	5	0.98	1.66	1.994	1.33	0.73
Picking guide	B (187)	A (100)	500-1040	6.1	1.94	0	3	0.88	1.73	1.121	0.46	1.33
Hunter b	B (187)	A (100)	500-1040	25.91	5.3	0	3	0.88	7.6	0.697	0.45	1.95

Table 20. Bundaberg region; calibration. Summary of model characteristics developed for using near infrared spectroscopy (NIRS) for predicting Brix in the ripe flesh of Calypso™ mango using spectra of the just-harvested, and of the ripe fruit (172 spectra). SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

Attributes	Range(nm)	Mean	SD	Outliers	PCs	R	RMSECV	SDR	Slope
Handgun 04									
Brix-green fruit spectra	726-919	15.6	1.7	3	10	0.90	0.74	2.2	0.84
Brix -ripe fruit spectra	726-919	15.57	1.66						
Shoebox									
Brix -green fruit spectra	726-919	15.57	1.66	6	5	0.93	0.6	2.767	0.88
Brix -ripe fruit spectra	726-919	15.57	1.66	5	5	0.92	0.65	2.554	0.85

Table 21. Bundaberg region; prediction. Results from predicting Brix in the ripe flesh of Calypso™ mango using near infrared spectroscopy (NIRS) of the just-harvested fruit. Different populations of fruit were used for calibration and for prediction. The NIRS spectra were obtained with the handgun unit 04 and the Shoebox. SD = standard deviation, PC = number of principle components , R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

	Population (number of spectra) used for											
Attributes	Calibration	Prediction	Range(nm)	Mean	SD	Outliers	PCs	R	RMSECV	SDR	Bias	Slope
iQ P04												
Brix-ripe fruit	Subset of C (100)	Subset of C (72)	726-919	15.9	1.59	0	8	0.89	0.86	1.849	-0.46	0.84
SHOEBOX												
Brix		Subset of C, green fruit (72)	726-919	15.86	1.59	0	6	0.92	0.71	2.239	0.37	0.86

5.1.2.3.4. What assessment routine is required to adequately estimate individual fruit maturity, and the average maturity of an orchard?

NIRS was fairly accurate in estimating average flesh colour (Table 22). However, the accuracy varied with block and farm. Also, NIRS consistently over-estimated flesh colour on the sun-exposed side of the fruit, possibly because of interference with the red skin colour on the exposed side. If the fruit shape had been distorted because of excessive sun exposure (especially obvious in the Katherine site), then NIRS again over-estimated flesh colour.

Table 22. Estimating flesh colour (using the Calypso Picking Guide scales of 1=no yellow to 11=very yellow) using the NIRS handgun unit 04 at Katherine (20 fruit per block) and Dimbulah (50 fruit). The results represent the average NIRS predicted and actual colour, as well as the readings for the sun-exposed, and shaded sides of the fruit. The NT NIRS model was developed using fruit from Darwin. The NQ model was based on the NT model, but adjusted by inclusion of fruit from Dimbulah.

Location	NIRS predicted		Actual flesh colour	NIRS predicted		Picking Guide	
	NT model	NQ model	(Picking guide)	Sun	Shaded	Sun	Shaded
Katherine							
7 November							
Block 1	6.7		6.8				
Block 4	5.9		5.5				
Block 16	6.4		5.6				

8 November							
Block 1	6.7		6.8	7.7	5.8	6.9	6.6
Block 4	5.9		5.5	7.0	4.9	5.6	5.3
Block 16	6.4		5.6	7.1	5.6	5.7	5.5
Dimbulah	6.7	6.5	6.3				

The handgun was accurate in estimating flesh colour 35-40% of the time but was accurate to within one colour unit 70-90% of the time (Table 23).

Therefore, the NIRS systems used in this study were sufficiently robust to allow estimation of average flesh colour of a batch of fruit under the following conditions:

- 100 fruit should be sampled to obtain a procession of 0.5 colour units.
- Two readings per fruit (one on either side of the fruit) should be taken.

- Any misshapen fruit should not be measured.

The current NIRS system is not accurate in estimating flesh colour of individual fruit. However, we estimate that the current level of accuracy would allow satisfactory separation of fruit into three colour unit bands, for example flesh colours between 3-6, 6-9, and 9 and above. Further investigations will continue next season to:

- Confirm whether NIRS can more accurately estimate dry matter of individual fruit, compared with flesh colour
- Determine if the near infrared portion only can be used for flesh colour, with a view to reducing interference from red skin pigments?

Table 23. Accuracy of estimating flesh colour using the NIRS handgun unit 04 (average of both sides of the fruit) at Katherine (from the three blocks on 7 November; total of 60 fruit) and Dimbulah (50 fruit). The results indicate the percentage of fruit where the flesh colour was either under- or over-estimated, compared with the actual flesh colour based on the Calypso Picking Guide.

Flesh colour units	Percentage of fruit		
	Katherine	Dimbulah	
	Darwin model	Darwin model	NQ model
Underestimated by 3	0	6	0
Underestimated by 2	3	0	0
Underestimated by 1	17	17	22
Accurate	**35**	**33**	**39**
Overestimated by 1	30	22	28
Overestimated by 2	13	11	6
Overestimated by 3	2	11	0
Accurate to within one unit	**82**	**72**	**89**

5.1.2.3.5. Is handgun accuracy compromised in the field by ambient light or temperature?

Preliminary results suggest little influence of fruit or unit temperature on estimated dry matter (Table 24). More work will be conducted this season to further test the accuracy of the hand unit under varying field conditions.

Table 24. Effect of NIRS handgun and fruit temperature on mean estimated dry matter (20 fruit), and the standard deviation (SD). The hand unit or the fruit were either held at room temperature, placed in the sun to in an oven before reading.

Treatment temperature		Light conditions	mean	SD
Unit	Fruit			
in building	in building	fluorescent	12.7	0.1
external ambient	external ambient	Shade	12.5	0.2
external ambient	external ambient	Sun	12.7	0.1
40^{o}C	in building	Shade	13.0	0.2

5.1.2.3.6. Can the handgun assist the grower identify patterns of variation in fruit maturity within the tree and across the block?

This aspect was not studied this season because of difficulties with the hand unit. Investigations will continue next season.

5.1.2.3.7. What assessment routine is required to adequately sample a tree?

Not studied this season. Investigations will continue next season.

5.1.2.3.8. How accurate are the current instructions given to picking teams to harvest the most mature fruit first? Can maturity be estimated by appearance?

For pickers to be able to select-harvest the more mature fruit, they must be able to differentiate maturity based on external appearance. To test this the research team and growers estimated flesh colour based on external appearance. The assessors developed their own criteria for judging, which were generally that more mature fruit had (in order of priority):

- a lighter green (green/yellow) background colour
- the cheeks had "filled out"
- The nose of the fruit was not pointed but had filled out.

Table 25 indicates that the members were relatively accurate in predicting average flesh colour of a batch of fruit based on external appearance. The two growers were generally more accurate than the researchers.

Table 25. The predicted flesh colour (using external appearance) compared with actual flesh colour (based on the Calypso Picking Guide) of Calypso mango harvested from several sites in the Northern Territory and North Queensland.

	External appearance		Actual flesh colour
	Researcher	Grower	(Picking guide)
Darwin	5.1		5.1
Katherine			
Block 1	6.0		6.8
Block 4	6.0		5.5
Block 16	5.8		5.6
Dimbulah			
Batch 1	5.3	6.4	6.3
Batch 2	**6.0**		**6.1**
Mareeba	6.3		7.3

On an individual fruit basis, flesh colour was accurately predicted only 6-40% of the time (Table 26, Table 27). However, 50-90% of fruit were within one colour unit of actual flesh colour, and most of the inaccuracy occurred because of underestimating the flesh colour (e.g., fruit that were considered immature, were actually mature). Thus, in relation to the risk of harvesting immature fruit during a select pick, if the average flesh colour of the fruit on the tree was seven, then up to 10% of the select-harvested fruit would have a flesh colour of five (that is, overestimated the flesh colour by two units).

Table 26. Accuracy of estimating flesh colour using external appearance with 20-80 fruit in each test. The results indicate the percentage of fruit where the flesh colour was either under- or over-estimated, compared with the actual flesh colour based on the Calypso Picking Guide.

	% of fruit				
	Katherine	Darwin	Dimbulah		Mareeba
	Researcher	Researcher	Researcher	Grower	Researcher
Underestimated by at least 4					10
Underestimated by 3	0	2	6	0	9
Underestimated by 2	8	1	39	6	20
Underestimated by 1	20	16	33	33	26
Accurate	**30**	**56**	**6**	**39**	**19**
Overestimated by 1	35	21	11	6	13
Overestimated by 2	5	4	0	11	4
Overestimated by 3	2	0	0	0	0
Accurate to within one unit	**85**	**93**	**50**	**78**	**58**

The results suggest potential for select harvesting the mature fruit based on external appearance. However,Table 28 suggests that commercially harvested fruit were only 1.2 colour units more yellow than fruit remaining on the select-harvested trees. The statistical analysis suggests that this difference is not significant. Figure 19 also shows slightly higher maturity of the harvested fruit, but there were also significant numbers of harvested fruit with flesh colour less than 7 (the commercial standard).

Table 27. The percentage of Calypso mango fruit that were accurately estimated to be mature (a flesh colour of at least seven) and immature, based on external appearance. In this instance, the grower described the fruit as either mature or immature.

	% of fruit	
	Grower	Researcher
Accurately predicted mature fruit	40	33
Accurately predicted immature fruit	35	38
Incorrectly estimated the fruit were mature	10	9
Incorrectly estimated the fruit were immature	15	21

Table 28. The average flesh colour of Calypso^{TM} mango fruit that had been harvested by a typical harvest team instructed to pick the most mature fruit, and the average flesh colour of the fruit remaining on the trees that had just been harvested. The numbers of fruit used in each test are presented.

	Darwin			Dimbulah		
	No of fruit	Mean	SD	No of fruit	Mean	SD
Harvested	440	7.5		25	6.0	1.3
Remaining on the tree	251	6.4		10	4.8	1.5

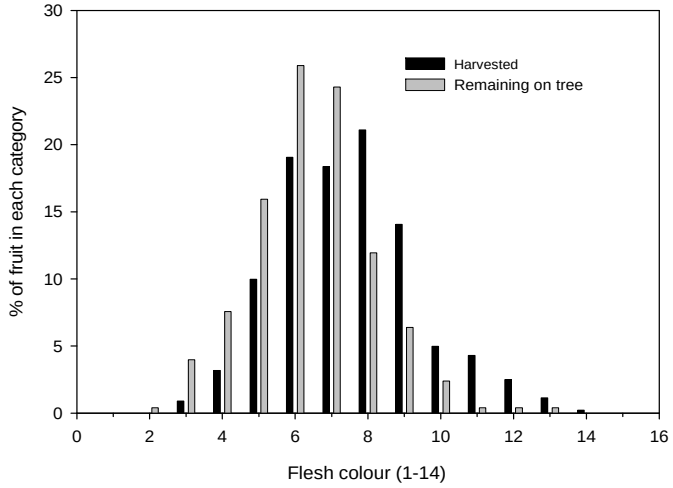


Figure 19 The percentage of Calypso™ mango fruit in each flesh colour category (based on the Calypso Picking Guide) using the NIRS hand gun. 440 fruit were sampled from the field bin containing fruit that had been picked by a typical picking crew operating under instructions to pick the most mature fruit. 251 fruit that remained on the same trees that had been harvested were also measured.

5.1.2.3.9. Can NIRS be used as an effective sorting system in the packhouse to increase the uniformity of fruit ripening and quality?

This was not specifically investigated this season. However the results from the above studies suggest that the current models were not very accurate in estimating individual fruit flesh colour, but should be sufficient to allow separation into three-colour-unit is less bands.

Further research along the following lines will confirm the suitability for NIRS for in-line sorting:

- To increase accuracy for estimating individual fruit maturity, consider developing a flesh colour model using only the near infrared spectrum (excluding the visible range which can be affected by skin pigments).
- Perhaps concentrate on predicting dry matter rather than flesh colour, which appears to be more accurate although more time-consuming for calibration.

5.1.2.4. Conclusions

- Both NIRS units (handgun and Shoebox) provided satisfactory models for prediction of average dry matter and flesh colour.
- The shoebox was consistently better than the handgun, indicating that further improvements to the handgun may be possible.
- Better models were obtained for prediction of dry matter than of flesh colour. This may be because of the use of the visible wavelengths in the model, causing interference from the red skin colour.
- NIRS consistently over-estimated flesh colour on the sun-exposed (blush) side of the fruit. Two readings on either side of the fruit are recommended.
- The handgun appears to be little influenced by fruit or unit temperature, or whether the readings are taken in the full sun or the shade. More detailed testing will be done next season.

- The models were acceptably accurate in predicting that average flesh colour and dry matter for a batch of fruit. The recommended sampling procedure for estimating the average maturity of a block is to measure 100 fruit, on both sides of the fruit. Any misshapen fruit should be avoided.
- Between 70-90% of the fruit were estimated to within one colour unit of actual flesh colour using NIRS. This may be sufficient for grading into 2-3 maturity categories in an in-line system, but more work is required to improve accuracy.
- To test whether it was possible to accurately identify more mature fruit by external fruit appearance, the flesh colour of harvested fruit was carefully estimated based on external appearance (skin colour, shape etc). Several researchers and growers were accurate 50-90% of the time to within one colour unit of actual flesh colour. This suggests that select picking of the more mature fruit in the early season harvests may be possible.
- We tested the ability to accurately harvest the more mature fruit under commercial conditions at two locations. In both instances the average flesh colour of commercially harvested fruit was only 0.9-1.2 colour units higher than fruit remaining on the tree, and over 15% of the harvested fruit had flesh colour of less than five. This illustrates, not so much the difficulty in training people to select-harvest, but the difficulty of getting consistency over time under commercial picking conditions.
- Further work will be conducted next season to:
    - determine whether technical changes to the handgun has improved its accuracy,
    - develop more accurate models for flesh colour, or simply use dry matter as the basis for further development,
    - develop accurate models for each of the major production regions,
    - determine the influence of production region/farm/block on prediction, and
    - evaluate in line systems for sorting for flavour and storage potential.

5.1.3. NIRS research 2008/9

5.1.3.1. Introduction

Flavour in mango fruit is determined by a number of factors, including sugars and volatiles content. However, a base attribute is a minimum carbohydrate content at harvest. Mango fruit accumulate starch during maturation which can then be used as an index of fruit maturity. Fruit % DM is an index of the total soluble sugar and starch concentration of the fruit. The Australian mango industry recommends a minimum DM of 14% at harvest (Meurant *et al*. 1999), which is generally related to sufficient ºBrix in the ripe fruit to provide acceptable flavour.

During ripening, starch converts to soluble sugars. Thus fruit % DM (mostly sum of starch and sugar) is relatively constant during ripening, while sugar concentration increases (and acid content decreases) (Subedi *et al*. 2007). Juice ºBrix is a measure of the total soluble solids content (%TSS) and is strongly related to sugars content. Higher % DM at harvest is related to higher ripe fruit ºBrix. Coles (www.coles.com.au) stipulate a quality standard of 14 ºBrix for fruit received to store. Flesh colour also becomes more yellow as the fruit matures, and this can also be used as an indicator of maturity.

Fruit maturity of the whole block or farm needs to be determined before commercial picking, or mature fruit easily identified on the trees to allow selective harvesting of these fruit. In some mango cultivars fruit external appearance changes as the fruit reach harvestable maturity. These changes include reduction in background green colour, ‘rounding’ of fruit shoulders, and “filling out” of the fruit. However, some cultivars such as Calypso^{TM}do not show these changes, or are unreliable or too subtle to allow pickers to economically use these characteristics to select these more mature fruit. As an alternative, block or farm maturity can be estimated by flesh colour or

flesh % DM, but these are destructive and time-consuming. A non-destructive system such as visible - short wavelength near infrared spectroscopy (SWNIRS) may have potential in this regard.

Near infrared spectroscopy can be used for rapid, non-destructive assessment of a number of plant constituents (Clark *et al.* 2003; Lammertyn *et al*. 2001). In 'Kensington Pride', it can predict % DM in just-harvested fruit (Guthrie and Walsh 1997) and ºBrix of ripe fruit using spectra collected at the just harvested stage (Subedi *et al*. 2007). Thus, this technology offers potential to assess harvested fruit maturity and final flavour, with potential application for in-field maturity assessment of fruit on the tree, and in-line assessment of final flavour.

A preliminary investigation was conducted in 2005/6 and 2006/07 in the Northern Territory and northern and southeast Queensland to evaluate the effectiveness of this technology in predicting % DM and flesh color at harvest, and ripe fruit ºBrix. This work was extended in 2007/08 to confirm the potential for non-destructive maturity testing of fruit on the tree, with a view to determining the start of commercial harvest and to guide the harvesting of more mature fruit.

The previous seasons work was based on a prototype portable NIRS unit (the "shoebox") and a first generation handheld unit (iQ P04). However, the iQ unit suffered hardware and software problems. Encouraging performance was achieved after changing to new software at the end of the Calypso^{TM}harvest season (in the Bundaberg district of Queensland). In the current season, the same P04 unit was used to address the questions raised during 2006/07 (as follows):

Instrument performance/reliability:

1. How consistent/repeatable is the iQ measurement (repeated measurement of the same sample)?
2. Can NIRS accurately predict flesh colour and % DM at harvest?
3. Can NIRS accurately predict ºBrix and flavour in the ripe fruit from spectra taken at harvest?
4. Is accuracy of the handgun compromised in the field by ambient light or temperature?
5. Do we need different models for each region/season?
6. Can we predict ripening times and shelf life? Near infrared spectroscopy can estimate fruit % DM, and fruit with higher % DM (more mature) within a given population generally ripen more quickly. Therefore it may be possible to predict days from harvest to eating ripe under uniform ripening conditions. It is also of interest to relate spectra to fruit shelf life (the days from when the fruit reaches eating soft to when they are no longer acceptable). It is less likely that NIRS will be successful in this area, but it is worth exploring.

Application issues:

1. Accuracy of current picking instructions for selectively harvesting the more mature fruit?

   Growers attempt to instruct their picking teams to harvest the more mature fruit first. This practice of selective picking is difficult to achieve with Calypso^{TM}mango because there are few external visual characteristics to indicate that the fruit has reached commercial maturity. We need to confirm how well growers/pickers can select the more mature fruit, and provide better guidelines for them if possible.
2. What assessment routine is required to assess whole or part of the tree maturity?

   The objective here is to describe maturity profiles within the tree, and to develop recommendations on the number and location of fruit required to estimate the average maturity of fruit on sectors of the tree.

   From previous research, we expect:

- sun-exposed fruit to have 1-3% higher dry matter, compared with fruit inside the canopy
- Western fruit in the Northern Territory to have lower dry matter than the eastern fruit (for north-south row orientation).
- Northern/western fruit in Queensland to have higher dry matter than southern fruit (assuming east-west row orientation).

3. What assessment routine is required to adequately sample an orchard?
   This would recommend a sampling strategy (number of fruit, number of trees) based on assessed variability (SD) to estimate whole block maturity.

These questions address the following aims:

1. Can the handgun assist the grower to identify when to start harvesting a block based on the current minimum maturity standards?
2. Can it help the grower identify patterns of variation in fruit maturity within the tree and across the block so that sound instructions can be given to pickers to ensure the most mature fruit are harvested first?
3. Can pickers consistently select the most mature fruit when given appropriate instructions on how to identify these fruit?
4. Can NIRS be used as an effective sorting system in the packhouse to increase the uniformity of fruit ripening and quality?

5.1.3.2. Materials and methods

5.1.3.2.1. Instrument performance/methodology

Unit repeatability

Before the start of the mango season, thirty scans of a white Teflon reference were obtained to estimate the repeatability of iQ P04, the Shoebox01 and an InSight (in-line unit used on packlines) unit. In addition, spectra and °Brix of 24 fruit of four apple cultivars were obtained using both units, and a PLSR regression model developed for each set of data.

Accuracy under field conditions

The performance of the iQ unit under a range of ambient conditions (constant fruit temperature, varying ambient light and gun temperature) was based on the data set from population 1 (Table 29). Fruit were selected from inside and outside the canopy, and from both sides of the tree. Of these fruit, some were exposed to full sun on the tree, and some were fully shaded. Fruit were selected from trees across the whole block to get maximum variation in fruit DM. Sample fruit were marked with a marker pen to locate the scan spots and each fruit was numbered. Both sides of the fruit were scanned.

Spectra were taken from the same location on the same fruit, under several conditions:

- Run 1 (on tree): Fruit still on the tree, taken during mid/late morning.
- Run 2 (fruit and iQ unit at ambient shade temperature, spectra collected of fruit in shade): The same fruit harvested and de-sapped under commercial conditions, and the fruit and handgun held in the shade in the packhouse for 2 h to reach similar temperatures (tested with an infrared thermometer).
- Run 3 (fruit and iQ unit at ambient shade temperature, spectra collected of fruit in full sun): Spectra were then collected of the fruit in sunlight (with fruit and iQ at pack-house temperature).
- Run 4 (fruit at ambient shade temperature, iQ unit heated by sun exposure, spectra collected of fruit in sun): The iQ unit was then allowed to heat for 2 h (to about 38°C) under full sunlight before spectra were again acquired of fruit at packhouse temperature but in sunlight.

Flesh colour and DM were then determined on the same position on the fruit as the spectra, and partial least square regression (PLSR) models developed.

Predicting flesh colour and % DM across farms

Fruit were harvested and all assessments done in the packhouse. Spectra were taken of the equatorial part of each cheek of each fruit. A 27 mm diameter, 10 mm deep core of fruit flesh was taken from where the spectrum was acquired, and the skin removed using a potato peeler. Flesh colour of the inside surface of the core plug was assessed using a Minolta Chromameter CR- 400 and the Calypso^{TM}Picking Guide. The % DM of the plug was then determined by weight loss following drying for 48 h in a forced air oven.

Table 29 Fruit populations (source farm and population statistics) used in NIRS modelling exercises for estimation of % DM of Calypso^{TM} mango in the 2007-8 season (hard green stage).

Popn.	Population (location, date)	n	Mean	SD
1	Acacia Hill Farm, Darwin, NT (12-18/10/07)	560	16.64	2.80
2	Oolloo Farm, Darwin, NT (22/10/07)	155	16.54	1.25
3	Oolloo Farm, Katherine, NT (20/11/07)	50	17.87	1.51
4	Dimbula, Mareeba, QLD(19/12/07)	332	15.07	1.91
5	Oolloo Farm, Bundaberg, QLD (22/01/08)	244	14.18	1.30
6	Simpsons Farms, Childers, QLD (30/01/08)	128	15.21	1.60
7	Oolloo Farm, Bundaberg, QLD (31/01/07)	287	16.61	3.06
1-7	1-7 Combined	1756	15.92	2.51

Table 30 Fruit populations (source farms and population statistics) used in NIRS modelling exercises for estimation of flesh colour of Calypso^{TM} mango in the 2007-8 season (hard green stage) (Calypso colour guide score).

Popn.	(Location, date	n	Mean	SD
1	Acacia Hill Farm, Darwin, NT (12-18/10/07)	560	5.39	1.80
2	Oolloo Farm, Darwin, NT (22/10/07)	155	5.33	0.81
3	Oolloo Farm, Katherine, NT (20/11/07)	504	5.47	1.47
4	Dimbula, Mareeba, QLD (19/12/07)	332	5.97	1.32
5	Oolloo Farm, Bundaberg, QLD (22/01/08)	420	6.60	1.78
6	Simpsons Farms, Childers, QLD (30/01/08)	128	7.82	2.11
7	Oolloo Farm, Bundaberg, QLD (31/01/07)	287	7.49	2.60
1-7	Combined	2099	5.58	1.46

Table 31 Fruit populations (source farms and population statistics) used in validation of NIRS models for estimation of % DM.

Popn.	Location, date	n	Mean	SD
8	Acacia Hills Farm – Darwin, NT (Activity 2 packhouse)	300	15.73	1.32
9	Acacia Hills Farm – Darwin, NT (Activity 2 packhouse)	274	15.09	1.08
10	Acacia Hills Farm – Darwin, NT (Activity 2)	910	15.69	1.37
11	Oolloo Farm, Bundaberg, QLD (Activity 2 Tree mapping)	537	15.20	1.14
12	Oolloo Farm, Bundaberg, QLD (Activity 3 and 4, sampling frame)	1000	15.41	0.92
13	Acacia Hills Farm – Darwin, NT (Activity 3 and 4, sampling frame)	815	15.65	1.28
14	Oolloo Farm, Bundaberg, QLD (Activity 5, monitoring DM increment pattern)	30	14.90	0.83

The PLSR calibration models were developed on data from seven populations (Table 29 and Table 30), and validated on independent populations (Table 31and Table 32) of Calypso^{TM} mango fruit. Note that population 7 was from the previous growing season (2006/07).

Table 32 Fruit populations (source farms and population statistics) used in validation of NIRS models for estimation of internal flesh colour (Calypso colour guide score).

Popn.	Growing districts Population (location, date)	n	Mean	SD

15	Acacia Hills Farm – Darwin, NT (Activity 1 packhouse)	300	5.15	0.88
16	Acacia Hills Farm – Darwin, NT (Activity 1 on tree)	274	4.39	0.80
17	Acacia Hills Farm – Darwin, NT (Activity 2)	910	15.69	1.37
18	Oolloo Farm, Bundaberg, QLD (Activity 2, Tree mapping)	537	6.97	1.11
19	Oolloo Farm, Bundaberg, QLD (Activity 3 and 4, sampling frame)	1000	7.55	0.78
20	Acacia Hills Farm – Darwin, NT (Activity 3 and 4, sampling frame)	815	4.97	1.02
21	Oolloo Farm, Bundaberg, QLD (Activity 5, monitoring flesh colour and DM increment pattern)	30	6.40	0.90

Predicting ripe fruit ºBrix

In this exercise we sought to confirm previous work that indicated that ripe stage ºBrix can be predicted using spectra collected from fruit at harvest, and to demonstrate method robustness. The exercise was performed with both the IQ and InSight units using populations in

Table 33.

Table 33 Populations used for modelling ripe stage ºBrix with spectra from hard green fruit using the iQ PO4 unit. Mean and SD of ripe stage ºBrix.

Popn.	Population (location, date)	n	Mean	SD
9	Oolloo Farm, Bundaberg, QLD Week 2 (DPI Nambur,07-2-08)	188	13.48	0.96
10	Oolloo Farm, Bundaberg, QLD Week 2 (CQU Rockhampton, 07-02-08)	165	11.67	0.77
9-10	Populations 9-10 combined	353	13.22	1.00
11	Oolloo Farm, Bundaberg, QLD (2007/08)	230	13.77	1.32
12	Oolloo Farm, Bundaberg, QLD (2007/08)	213	13.27	1.36
13	Oolloo Farm Bundaberg, QLD (2007)	172	15.57	1.66
11-13	11-13. Populations 11-13 combined	615	14.10	1.72

Fruit with a good DM range were selected using the DM model developed in section 5.1.3.3.1. Fruit were scanned on the day of harvest. For population 10, fruit were allowed to ripen at 20°C to a consistent firmness.

To assess firmness an acoustic velocity technique was used (in house developed equipment, Kerry Walsh, Central Queensland University; Plate 6). Fruit with an acoustic velocity of less than 30 m.s-1 was considered to have reached eating soft (stage 3, ‘soft’, on industry scale of 0 to 4 based on hand/finger pressure).

Plate 6 Acoustic velocity unit used to assess the eating soft stage of Calypso mango fruit.

When ripe, juice was extracted from a core taken from the scanned area of the fruit as described above for %DM and colour determination in 'hard green' fruit. ºBrix of the juice was measured using a Bellingham and Stanley RFM 320 temperature compensated refractometer. Fruit of populations 9 and 10 were used in shelf and storage life trials (see below), with juice ºBrix assessed at the end of each trial.

Do we need different models for each region/season?

Spectra, % DM and flesh colour were acquired for six representative populations from different production districts and across the mango growing season (Table 29 and Table 30). The PLSR model robustness across the populations was assessed. Recommendations were developed on the need for separate models for each farm/region based on the performance of these models and the ability of one population model to accurately predict % DM and flesh colour on fruit from other populations.

Predicting time to eating soft and shelf life

This work was based on spectra collected using both iQ (populations 9 and 10) and InSight units (populations 8 to 10) (Table 34). Spectra were acquired of each cheek of each fruit at harvest for populations 8 and 9 (approximately 90 fruit per population), harvested one week apart from the same farm. Models developed in section "Predicting the flresh colour and DM across farms" were used to estimate the % DM of these fruit. The fruit were shipped to the Maroochy Research Station and Central Queensland University and ripened at 20°C without ethylene treatment. The days from harvest to eating soft were recorded ('time to ripe') and the fruit then held at 20°C until the fruit were no longer acceptable (as determined by external appearance). 'Shelf life' was recorded as the days from eating soft to unacceptable condition.

PLSR models were based on spectra recorded at the hard green stage, and both time to eating soft and shelf life.

Table 34 Populations used in modelling of 'time to ripeness' and 'shelf life' from spectra collected of fruit at the hard green stage.

Pop.	Population (location, date)	% DM			Score	
		n	Mean	SD	Mean	SD
8	Oolloo Farm, Bundaberg Week 1 (DPI Nambour, 31-01-08)	177	12.9	0.94	6.0	0.96
9	Oolloo Farm, Bundaberg, QLD Week 2 (DPI Nambour,07-02-08)	188	13.5	0.96	7.2	1.04
10	Oolloo Farm, Bundaberg, QLD Week 2 (CQU Rockhampton, 07-2-8)	165	11.7	0.77	7.0	1.12
8-10	8-10. Populations	532	12.7	1.17	7.1	1.04

5.1.3.2.2. Application issues

Testing manager and picker estimation of maturity

Manager/picker estimation of fruit maturity for selective harvesting was tested on two occasions:

- Picker estimation of fruit maturity was assessed near the start of the season at a Darwin farm. Pickers were instructed to harvest the most mature fruit based on skin colour, fruit shape and fruit size guidelines and demonstrations by the farm manager. The iQ unit, calibrated for prediction of % DM and flesh colour using data of populations 1 - 2 was used to predict these attributes of harvested fruit (sampled from the picking bin, n= 50) and from fruit remaining on the harvested trees (n= 50). This was undertaken in the morning when the pickers were picking from the west side of the trees, and in the afternoon when they were picking on the east side.
- In Bundaberg, the farm manager decided a given field was ready for harvest based on existing maturity estimates, and instructed the picking crew to harvest all fruit in the block. Fruit were randomly selected from four of the harvested bins and assessed using the IQ unit (calibrated using the combined data of populations 1 - 7) for DM and flesh colour (n = 150 from each bin).

Assessing whole or part tree fruit maturity

At a Darwin farm, the IQ unit (calibrated based on the combined data of populations 1 and 2) was used to estimate % DM and flesh colour of both cheeks of all fruit on each of four representative trees. The location of the fruit in the canopy (row orientation, aspect (N/S/E/W), height (upper / middle / lower), and canopy position (inner / outer)) was recorded.

In Bundaberg, the IQ unit (calibrated based on the combined data of populations 1 to 7) was used to estimate % DM and flesh colour of the 'blush' cheek of 10 fruit in each of nine canopy positions; four aspects (N/S/E/W), outer canopy at two heights (upper/lower), and from inside the canopy. Six trees were assessed.

These data was used to estimate variation in fruit maturity within a given tree, and so develop an assessment protocol to estimate which parts of the tree contain the more mature fruit, and which tree section should be used to estimate %DM or flesh colour using the iQ unit. The number of fruit required to reliably estimate the maturity stage of a given tree was based on an estimate of the SD of the attributes of % DM and flesh colour (eqn. 1).

Assessing block or maturity zone fruit maturity

This exercise was conducted at Acacia Hills Farm and Oolloo Farm Bundaberg.

At Acacia Hills, trees were top-worked, 6 years old, approximately 4 m high, with overlapping canopies. A total of 44 trees were examined, with 10 – 27 fruit selected from around the mid height of each tree, depending on tree size and fruit number per tree. Every seventh tree in each of seven adjacent rows was assessed.

In Bundaberg, trees were assessed in two adjacent blocks (Blocks 19 and 21) and another separate block (Block 3). Trees in Blocks 19 and 21 were seedling grafted, 4 years old, approximately 2.5 and 3 m high respectively, with canopies touching but not overlapping. Trees in Blocks 3 were top-worked, more than 6 years old, approximately 5 m high, with canopies overlapping. Ten fruit were scanned from mid-height on the eastern side of each tree (based on the results from Acacia Hills Farm above). In each block, second adjacent rows, and every the fifth tree in each row was assessed, giving a total of 100 trees across the three blocks.

Changes during fruit growth

Thirty fruit were labelled on a tree in Oolloo Farm Bundaberg on the 29/01/08, and assessed repetitively (three events) at five day intervals to assess the capability of a hand held unit to assess flesh colour and DM change over time.

5.1.3.3. Results and discussion

5.1.3.3.1. Instrument performance/methodology

Unit repeatability

For repeated measurement of a reference (teflon tile), a standard deviation (SD) of 0.7 mAbs was achieved with the InSight unit, 0.3 mAbs with the earlier generation 'shoebox' unit and 20 mAbs using the iQ unit (Figure 20-Figure 22). Higher values indicate reduced accuracy and repeatability.

The portable unit takes several reference measurements with every sample, in contrast to the InSight unit. These references are required to accommodate changing ambient conditions (e.g. light level) in the field, but represent a source of noise. As a result the 'new generation' handheld units (model iQ) did not achieve the performance level of the prototype (‘shoebox’) unit or the InSight unit.

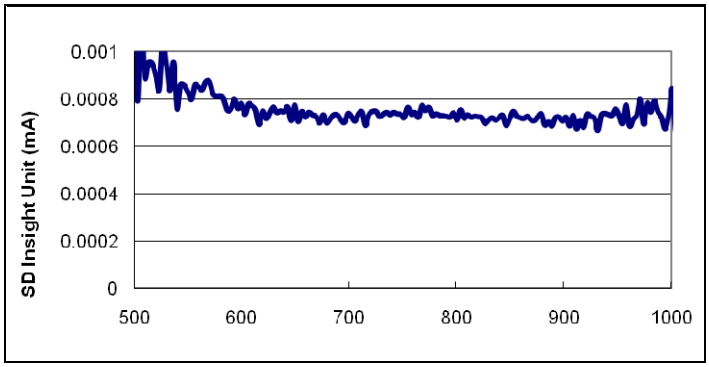


Figure 20 Insight unit: Repeatability (SD of Absorbance for 30 repeated measurements of a white tile).

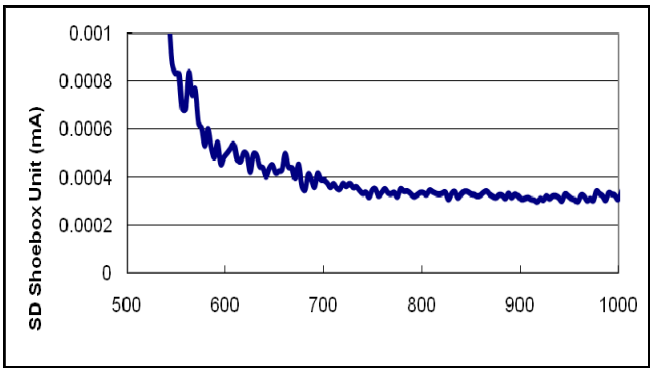


Figure 21 Shoebox unit: Repeatability (SD of Absorbance for 30 repeated measurements of a white tile).

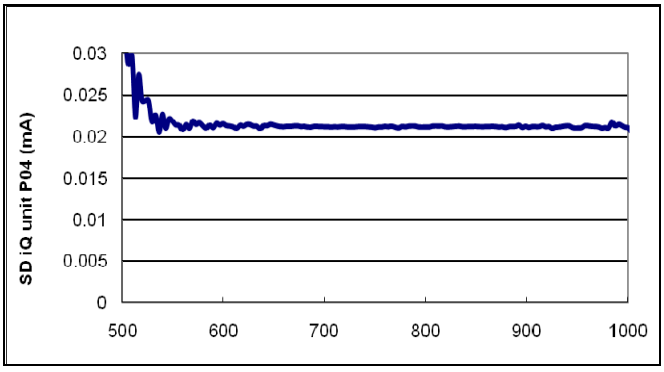


Figure 22 iQ unit P04: Repeatibility (SD of Absorbance for 30 repeated measurements of a white tile).

However, ability to predict ºBrix in apple fruit was only marginally different between the iQ and InSight units. For one population of apple fruit (n= 48) under laboratory conditions, a regression coefficient (R) of 0.976 was achieved with the InSight unit (Figure 23), and 0.967 with the iQ unit (Figure 24). Lower values suggest less accurate prediction, but the small difference in R between the two units suggests that the lower repeatability of the iQ unit has only a small effect on accuracy of prediction. We conclude that the lower repeatability of the iQ unit is not a limitation for use of the unit for fruit prediction.

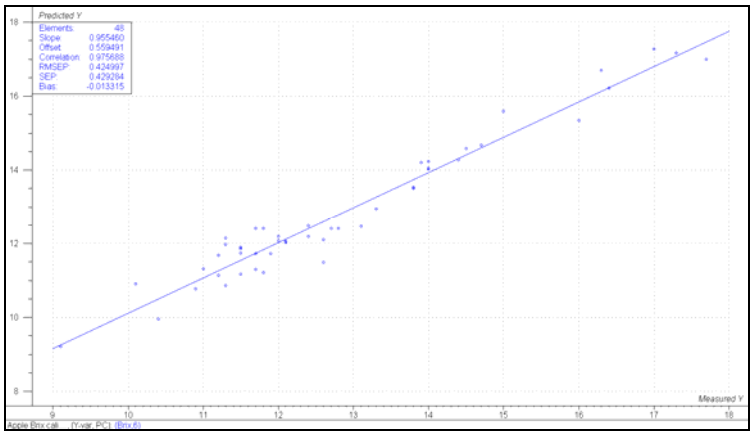


Figure 23 Insight Unit calibration model performance of apple ºBrix.

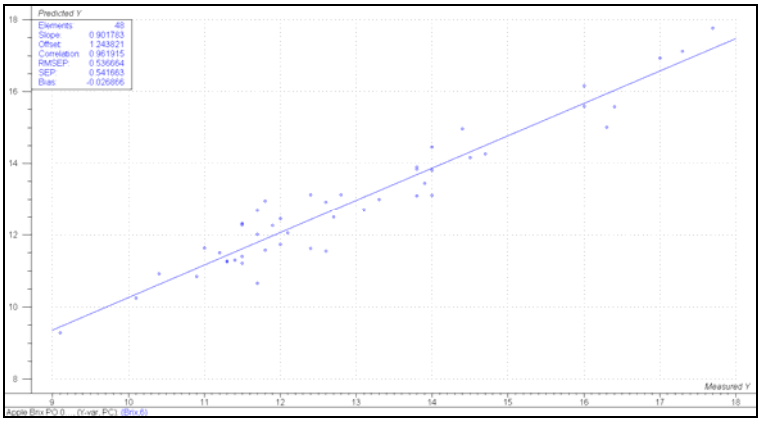


Figure 24 iQ P04 Unit calibration model performance of apple ºBrix.

Accuracy under field conditions

From population 1 a subset was used with fruit and iQ held under various environmental conditions (n = 50 fruit, spectra collected from each cheek of every fruit). For this sub-population, a mean and SD of % DM was 16.2 and 2.78, respectively, while the flesh colour mean and SD was 5.3 and 1.74, respectively.

The PLSR model performance for % DM was always better than for internal flesh colour (Table 35). However, model performance of flesh colour was also within the acceptable range (R > 0.86).

PLSR regression statistics were not markedly different for spectra acquired under the various environmental conditions (Table 35), and the mean estimated % DM and flesh colour were identical under these differing conditions.

Table 35 Calibration model statistics on mango % DM and flesh colour, assessed under various environmental conditions. Spectra were acquired using iQ P04 of fruit on the tree (run 1);

of fruit in packhouse shade (run 2), of fruit at packhouse temperature but in ambient sunlight (run 3) and using the iQ unit allowed to heat to 38°C and held up to directly face the sun (run 4). Mean and SD of % DM was 16.2 and 2.78, respectively, while mean and SD of flesh colour was 5.3 and 1.74, respectively

Run	n	No of factors	No of Outliers	R	RMSECV
% DM					
1. In field	100	7	2	0.95	0.89
2. Cool fruit, cool iQ, shade	100	7	4	0.95	0.85
3. Cool fruit, cool iQ, sun	100	7	2	0.96	0.76
4. Cool fruit, hot iQ, sun	100	6	2	0.94	0.83
1-4. combined	400	7	10	0.96	0.78
Flesh colour					
1. In field	100	4	5	0.90	0.81
2. Cool fruit, cool iQ, shade	100	3	5	0.90	0.79
3. Cool fruit, cool iQ, sun	100	4	6	0.88	0.80
4. Cool fruit, hot iQ, sun	100	4	2	0.88	0.78
1-4. combined	400	6	13	0.90	0.76

SD = standard deviation, PC = number of principle components, R = correlation coefficient, RMSECV/P = root mean square error of cross validation/ prediction.

A model developed on populations 2 to 6 was used in prediction using the data from runs 1 to 4 of population 1 (

Table 36). Prediction results for spectra collected of fruit under differing conditions were similar in terms of R and bias (except for flesh colour for run 4, for which bias was increased).

Based on these results, the unit can be used with fruit and instrument at a range of temperatures and ambient light conditions, however the instrument should be kept as cool as possible (e.g. storage in shade rather than in sun). Use of the instrument on exceptionally hot days is not recommended.

Predicting flesh colour and % DM across farms

A 'moving windows' repetitive PLS approach was used to define the optimum wavelength region for PLSR modelling. For flesh % DM the optimal wavelength region was 735-975 nm, while for flesh colour the optimal wavelength region was 726-915 nm (data not shown).

Dry matter was better modelled than flesh colour (Table 37 ; e.g. higher R value).

A model created using Population 1 data predicted % DM in five independent populations reasonably well (RMSEP generally < 1), including a population (population 7) from a different growing season (Table 38). On this basis, it is recommended that a single model could be used across all growing regions.

Table 36 Prediction performance on % DM and internal flesh colour (Calypso Picking Guide) of population 1, runs 1 to 4, assessed using models developed on data of populations 2 to 6. . Calibration models statistics for % DM were n= 1319, mean = 15.84, SD = 1.85, RMSECV = 0.75; SDR = 2.47, bias = 0.0. Calibration model statistics for flesh colour were n= 1113, mean = 5.67, SD = 1.28; RMSECV = 0.72; SDR = 1.78; bias = 0.0. Population statistics

Pred set	n	Mean	SD	R	RMSEP	SDR	Bias
% DM							
Pop 1							
1. In field	100	16.20	2.78	0.95	0.95	2.93	0.84
2. Cool fruit, cool iQ, shade	100	16.20	2.78	0.95	0.86	3.23	0.86
3. Cool fruit, cool iQ, sun	100	16.20	2.78	0.95	0.87	3.20	0.86
4. Cool fruit, hot iQ, sun	100	16.20	2.78	0.94	0.83	3.35	0.90
1.-4. combined	400	16.20	2.78	0.95	0.89	3.12	0.85
Flesh colour							
Pop 1							
1. In field	100	5.33	1.74	0.85	1.13	1.54	0.39
2. Cool fruit, cool iQ, shade	100	5.33	1.74	0.84	1.25	1.39	0.30
3. Cool fruit, cool iQ, sun	100	5.33	1.74	0.84	1.11	1.60	0.16
4. Cool fruit, hot iQ, sun	100	5.33	1.74	0.85	1.35	1.29	0.82
1.-4. combined	400	5.33	1.74	0.82	1.22	1.43	0.34

SD = standard deviation, PC = number of principle components, R = correlation coefficient, RMSECV = root mean square error of cross validation/ prediction, SDR = SD/RMSECV/P.

Golic and Walsh (2006) describe PLSR-NIRS model robustness for prediction of TSS of stonefruit. Models could be used across varieties through the growing season and between growing seasons if the model calibration population adequately represented the variation present in the new populations. Problems arose with prediction of certain varieties (e.g. low acid varieties) and with populations of substantially different TSS levels to that of the calibration set, generally in terms of bias rather than R. It is expected that similar caveats will exist to the robustness of the Calypso^{TM} mango % DM model. That is, if % DM levels are substantially different in different growing districts or seasons, the model prediction may suffer bias.

A quality control procedure is therefore recommended for the next few seasons at least. This would involve confirming the accuracy of the unit estimates of % DM and flesh colour by scanning about 20 fruit then measuring actual flesh colour and % DM for each fruit and averaging the results from the unit estimates and actual measurements. This should be done several times during the season and for each region. It should not be necessary to repeat on every farm in each region, but may be useful to do so. If the unit is not accurately predicting actual maturity, then the model should be updated by including the data from the 20 fruit tested into the calibration model as described in Subedi *et al*. (2007) This is offered as a paid service through the instrument vendors.

Prediction of flesh colour was not as robust, with large bias values skewing RMSEP values. It is recommended that a single model can not be used across all growing districts, and that a model updating or bias adjustment procedure is required. Model performance should be checked on each farm, as outlined above.

Predicting ripe fruit ºBrix

As expected, the on-line InSight unit performed slightly better than the handheld iQ unit for predicting ºBrix.

The % DM was well predicted in fruit at hard green stage, and ripe stage ºBrix is well correlated to % DM at hard green stage (Saranwong *et al.* 2004; Subedi *et al.* 2007). Therefore NIRS should be able to predict ripe fruit ºBrix by scanning fruit at harvest. Indeed, calibration model statistics for ºBrix of ripe fruit based on spectra recorded from just harvested fruit were generally acceptable (RMSECV <0.76 % ºBrix) (

Table 39). However, prediction of ripe fruit ºBrix from hard green fruit spectra was poor across independent populations (e.g. SDR<2) (Table 40). This result is attributable to the low SD (small range in ºBrix within each population). RMSEP was generally <1 ºBrix, with bias <0.5 ºBrix for the iQ unit.

Table 37 Statistics summary for PLSR models of % DM and flesh colour (Calypso Picking Guide). Models are based on second derivative of absorbance (d2A) spectra obtained with the hand held iQ unit P04.

Population	n	Mean	SD	No of factors	No of outliers	R	RMSECV
% DM							
1	560	16.6	2.8	7	13	0.96	0.78
2	155	16.5	1.25	8	6	0.85	0.65
3	50	17.9	1.51	9	2	0.85	0.78
4	332	15.1	1.91	9	7	0.90	0.78
5	244	14.2	1.30	10	2	0.90	0.59
6	128	15.2	1.60	9	3	0.93	0.60
7	287	16.6	3.06	5	6	0.94	1.05
1-7	1756	15.9	2.51	8	23	0.93	0.85
Flesh colour							
1	560	5.4	1.80	6	7	0.90	0.80
2	155	5.3	0.81	7	0	0.61	0.65
3	504	5.5	1.47	8	11	0.74	0.97
4	332	6.0	1.32	8	7	0.88	0.59
5	420	6.6	1.78	4	3	0.85	0.91
6	128	7.8	2.11	9	3	0.93	0.60
7	287	7.5	2.60	4	10	0.88	1.19
1-7	2155	6.0	1.88	7	58	0.82	0.97

n = number of samples per population, SD = standard deviation, PC = number of principle components, R = correlation coefficient, RMSECV = root mean square error of cross validation.

Table 38 PLSR prediction model statistics for a model developed from population 1 data used in prediction of separate populations for the attributes of % DM and internal flesh colour.

Predicted popn.	N	Mean	SD	Factors	R	RMSEP	SDR	Bias
% DM								
1	560	16.6	2.8	7	0.96	0.82	3.41	0.00
2	155	16.3	1.25	7	0.75	1.1	1.14	-0.64
3	50	17.9	1.5	7	0.91	0.92	1.63	-0.55
4	332	15.1	1.90	7	0.87	1.22	1.56	0.78
5	244	14.5	1.49	7	0.78	0.84	1.77	0.16
6	128	14.5	1.49	7	0.83	0.89	1.67	0.19
7	287	16.6	3.06	7	0.94	1.06	2.89	0.01
Flesh colour								
1	560	5.4	1.80	6	0.9	0.78	2.31	-0.01
2	155	5.3	0.81	6	0.51	1.04	0.78	-0.38
3	504	5.5	1.46	6	0.62	1.28	1.14	0.55
4	332	6.0	2.32	6	0.81	0.83	2.80	0.21
5	420	6.6	1.78	6	0.78	2.44	0.73	2.17
6	128	7.8	2.11	6	0.57	3.97	0.53	3.57
7	287	7.5	2.60	6	0.8	2.46	1.06	1.87

It is recommended that this issue be re-considered using a model developed using with a wider range of % DM and thus ripe fruit ºBrix values (e.g. populations 9 to 13). Alternatively, as the link between DM and final stage ºBrix is well established, it may be appropriate to simply adopt specifications on % DM.

Table 39 Partial least squares regression (PLSR) calibration model statistics based on second derivative of absorbance (d2A) spectra from fruit harvested at hard green stage for the attributes of ºBrix in fruit at fully ripe stage.

Instrument	Population	n	Mean (ºBrix)	SD	No of factors	No of outliers	R	RMSECV
InSight	8	177	12.9	0.94	5	1	0.87	0.45
	9	188	13.5	0.96	7	1	0.86	0.49
	10	165	11.7	0.77	7	1	0.85	0.40
	8-10	532	12.7	1.17	8	1	0.90	0.50
iQ PO 4	9	188	13.5	0.96	5	10	0.73	0.65
	10	165	11.7	0.77	8	8	0.80	0.56
	9–10	353	13.2	1.00	10	15	0.80	0.60
	11	230	13.8	1.32	9	9	0.84	0.71
	12	213	13.3	1.36	7	2	0.83	0.75
	13	172	15.6	1.66	8	3	0.89	0.76
	11-13	615	14.1	1.72	7	7	0.90	0.76

Table 40 PLSR prediction model statistics for ºBrix of ripe fruit using spectra of hard green fruit using unit iQ P04 and an Insight unit.

Instrument	Cal set	Pred. set	n	Mean (ºBrix)	SD	Factors	R	RMSEP	SDR	Bias
InSight	8	9	188	13.5	0.96	5	0.83	1.06	0.91	0.92
	8	10	165	11.7	0.77	5	0.74	0.63	1.22	0.33
	8+ 9	10	165	11.7	0.77	7	0.73	0.86	0.92	0.68
iQ PO4	9	10	165	11.7	0.77	8	0.69	0.99	0.78	0.70
	13	11	230	13.8	1.32	8	0.77	0.91	1.45	0.23
	13	12	213	13.3	1.36	8	0.80	0.91	1.50	0.21
	11+13	12	213	13.3	1.36	6	0.82	0.92	1.48	0.48

SD = standard deviation, PC = number of principle components, R = correlation coefficient, RMSECV = root mean square error of cross validation, SDR = SD/RMSECV

Predicting time to eating soft, and shelf life

Dry matter (NIRS estimated) was related to flesh colour (NIRS estimated) (Figure 25) for the population used in the shelf life trial (population 14). This confirms the relation between flesh colour and % DM.

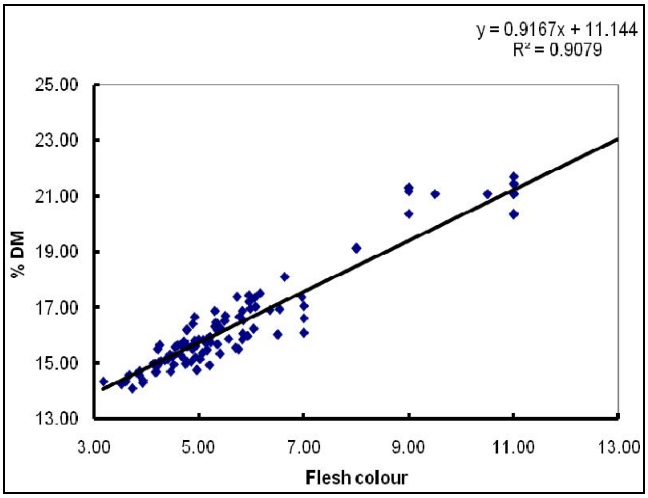


Figure 25 Relationship between NIR predicted DM and NIR predicted flesh colour for population 14.

Ripening time (from harvest to eating soft) was weakly related to NIRS predicted flesh colour at harvest (R^2 = 0.4) (Figure 26) and to DM at harvest (R^2 = 0.51) (data not shown) (Population 9 + 10).

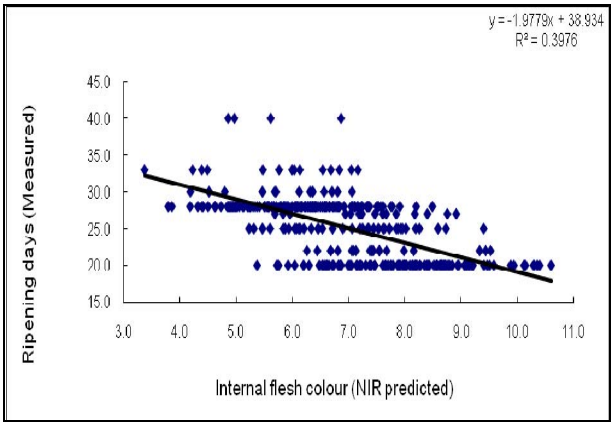


Figure 26 Relation between ripening time (days from harvest to eating soft) and NIRS estimated flesh colour.

Shelf-life (days from ripe to unacceptable was weakly related to % DM (R^2 = 0.5) (Figure 27) and flesh colour (R^2 = 0.39) (data not shown) (Population 9 + 10).

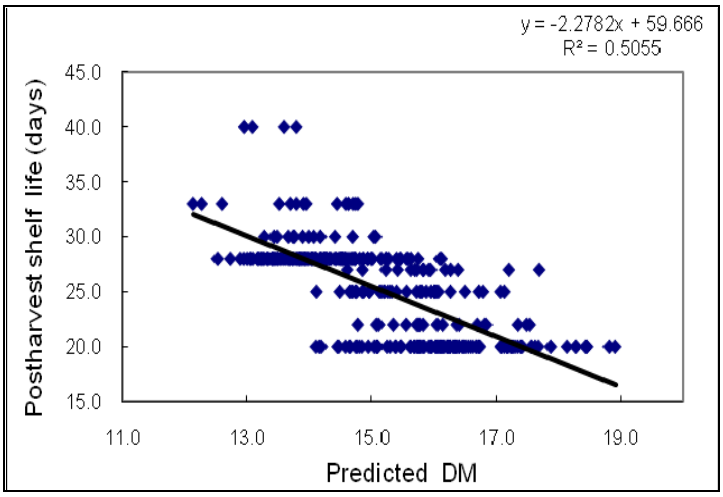


Figure 27 Relation between shelf life (time from eating soft to unacceptable external appearance) and NIRS predicted DM.

A PLSR model was created for ripening time (ie. time from harvest to eating soft) (R^2 = 0.71, RMSECV= 1.96, number of factors = 6) (Figure 28). The fruit were also divided into three dry matter categories using NIRS. At the mid ripe stage the low DM group had more green colour on the skin, and the highest dry matter group had a more orange skin colour (Plate 7). This suggests it is possible that days to eating soft can be predicted from spectra of fruit at harvest.

A PLSR model was created on shelf life (time from eating soft to unacceptable external appearance) (R^2= 0.74, RMSECV = 1.82, # of factors = 5) (calibration scatter plot, data not shown). Robustness of this model for prediction of independent data sets was not tested.

5.1.3.3.2. Application issues

Testing manager and picker estimation of maturity

In Darwin, harvested fruit were only slightly more mature than fruit left on the tree (mean difference of 0.3 in the morning and 1.0 in the afternoon for both flesh colour and % DM) (

Table 41 and Figure 29). However, there was a large overlap in maturity of fruit in the bin and remaining on the trees. These results are consistent with the 2006/7 season results, and again suggest that under commercial conditions picking crews are unable to accurately select more mature fruit. It is possible that the picking crews did not receive sufficient training or were not following instructions, but the fact that similar results were obtained on three occasions supports our conclusions.

We suggest that select harvesting based on fruit external appearance not be used as a standard practice, and that identifying the most mature trees/areas of the farm be identified using NIRS, and these trees/areas be strip-picked.

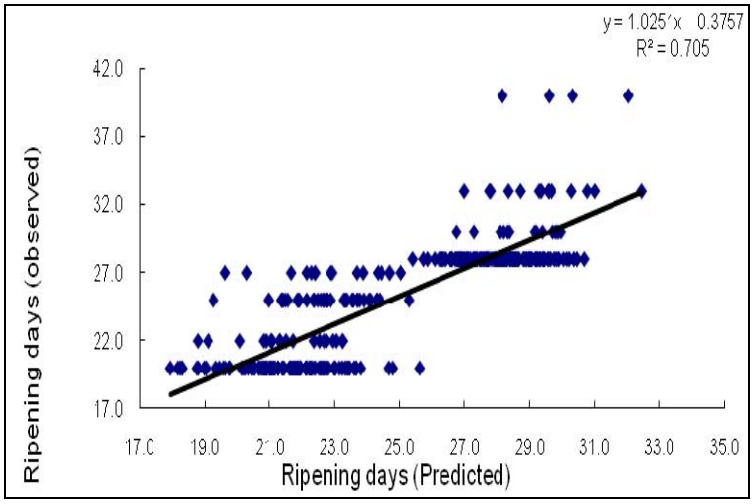


Figure 28 Relation between predicted and observed days from harvest to eating soft using fruit shown in Plate 7.

Plate 7 Image of Calypso™ mango fruit sorted at harvest by the SWNIRS PLSR DM model into three dry matter categories of (from left to right) less than 14 %DM, 14-16 %DM and more than 16 %DM.

Table 41 NIRS predicted % DM and flesh colour for harvested fruit and fruit remaining on tree following commercial harvest of Calypso™mango at a Calypso™Darwin farm. The pickers were instructed to harvest the most mature fruit based on external appearance.

Time of Picking	Statistics	Flesh colour		% DM	
		in bin	on tree	in bin	on tree
Morning	Mean	4.9	4.6	15.5	15.2
	SD	0.8	0.8	1.3	1.0
	Max	7.0	6.5	18.9	18.3
	Min	2.7	2.2	11.8	12.7
Afternoon	Mean	5.4	4.4	16.0	15.0
	SD	0.9	0.9	1.3	1.1
	Max	8.3	6.6	21.6	19.4
	Min	3.5	2.1	13.3	12.6

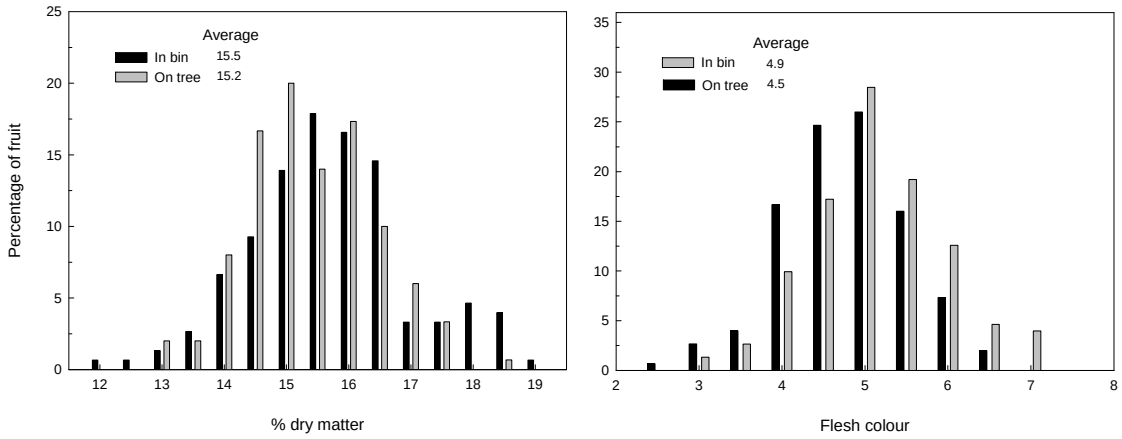


Figure 29 Darwin, morning pick: The percentage of Calypso mango fruit in each % dry matter flesh colour category (based on the Calypso Picking Guide) using the NIRS hand gun. About 200 fruit were sampled from the field bin containing fruit that had been picked by a typical picking crew operating under instructions to pick the most mature fruit. The fruit that remained on the same trees that had been harvested were also measured.

In Bundaberg, the iQ predicted % DM of 14.8±1.1 (SD; n = 600 fruit) and flesh colour of 7.1±1.0 (n = 600) (Figure 30) indicates that the manager had predicted correctly that the block was ready for harvesting based on a maturity standard of 14% DM and flesh colour 7. However, about 23 % of the fruit were at 14% DM or lower, and 29% of the fruit were below flesh colour 7.

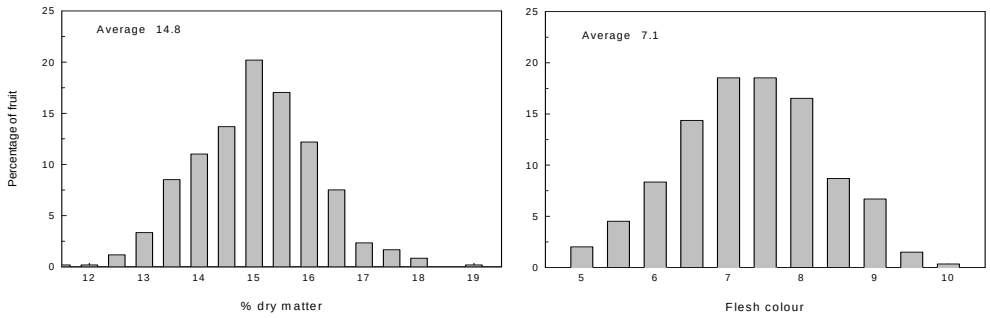


Figure 30 Bundaberg: The percentage of Calypso mango fruit in each % dry matter and flesh colour category (based on the Calypso Picking Guide) using the NIRS hand gun. About 200 fruit were sampled from the field bin containing fruit that had been picked by a typical picking crew instructed to strip harvest the trees on the assumption that the fruit were mature.

Assessing whole or part tree fruit maturity

At the Darwin farm, variation in fruit (NIR predicted), flesh colour and % DM within each tree was considered in terms of aspect (N/S/E/W), canopy height and canopy position (inner vs. outer). Outer and inner canopy fruit had similar maturity (average across all aspects and canopy heights, outer canopy DM 15.7±1.4; inner canopy DM 15.6±1.4; outer canopy flesh colour 5.0±1.0; inner canopy 4.8±1.1. For the blush side only, the results were: 15.7±1.3 % DM for the outer canopy and 15.8±1.4 inner canopy, and 5.2±1.0 outer canopy flesh colour and 4.9±1.2 inner canopy). We believe the similarity was due to the relatively open canopy of these trees.

Analysis of variance (Genstat) on flesh colour and % DM indicated significant differences between fruit at different heights in the canopy (Table 42; $P<0.001$ for both attributes). Upper canopy fruit had higher % DM and flesh colour at all aspects, but there was little difference between fruit in the mid and lower canopy. There were no significant differences between different aspects of the canopy ($P<0.11$ for both attributes), and the interaction between canopy height and aspect was not significant for either attribute.

Table 42 Darwin: Effect of canopy aspect and location on NIRS predicted % DM and flesh colour of Calypso^{TM}mango fruit in four trees (all fruit assessed on each tree).

Canopy aspect	Canopy height		
	Upper	Mid	Lower
% DM			
North	16.5	15.7	15.6
East	16.0	15.6	15.9
South	15.9	15.6	15.7
West	16.2	15.0	15.3
Flesh colour			
North	5.9	5.2	5.0
East	5.5	5.2	5.3
South	5.7	5.2	5.4
West	5.5	4.4	4.8

At the Bundaberg site, fruit on the inside of the canopy had lower % DM than those on the outside of the canopy ($P<0.001$), most likely because of the larger and denser tree canopy. Fruit from the upper canopy had higher % DM than those from the lower canopy (Table 43; $P<0.001$). There were no % DM differences in fruit from the different aspects of the canopy. Flesh colour showed similar trends to % DM. East and south fruit had significantly higher flesh colour than west fruit ($P<0.039$) and outer fruit had higher flesh colour than inner fruit ($P<0.001$). There were no differences with canopy height.

For Bundaberg, the most mature fruit were located in the upper, outer canopy, and especially on the north and east quadrants of the upper canopy. The highest DM fruit, and thus presumably destined to become the highest eating quality fruit, were thus located in the outer canopy of the upper half of the tree.

In conclusion, fruit from the upper canopy are usually more mature than fruit from the lower, and inner canopy. This is likely to be more pronounced in larger, and denser canopy trees. For the first harvest of a given block (hopefully a given maturity zone), picking crews should be instructed to strip all fruit from the upper, outer parts of the tree. The iQ unit could be used to confirm these fruit maturity zones to aid in select harvesting.

Having established where on the tree to sample fruit, the next question is: How many fruit should be sampled to adequately represent the maturity of fruit in that canopy zone? The following relationship can be used:

$$n = (t.\ SD / \varepsilon)^2 \qquad \text{……. equation 1}$$

Where n is the number of samples required, SD is the standard deviation of the population, ε is the uncertainty of the measurement, and t = 1.96 (for a probability of a larger value of t of 0.05 and an infinite number of degrees of freedom),

At Bundaberg, 10 fruit were sampled from the outer canopy of the north east quadrant of 100 trees. The SD of % DM for each tree varied from 0.37 to 1.36, with mean of 0.72 (data not shown), with the SD on DM correlated to that for flesh colour (Figure 31). Therefore, for a measurement uncertainty of 0.5 % DM, between 2 and 29 fruit, average 11 (using eqn. 1), are required to represent % DM for a sector of the tree.

The SD on average flesh colour of 10 fruit per tree across the 100 trees in the Bundaberg blocks ranged from 0.28 to 1.28, with a mean of 0.72 colour units. Therefore, for a measurement uncertainty of 0.5 colour units, between 1 and 25 fruit, average 8, are required to represent fruit flesh colour for a given tree.

On this basis we recommend sampling of at least 10 fruit from a given tree. These fruit should be taken from the most mature sector of each tree, nominally the outer, northern canopy (although this may vary by canopy architecture). The next question is how many trees should be assessed to estimate the average fruit maturity within a given maturity zone.

Table 43 Effect of canopy aspect and location on the fruit % DM and flesh colour of Calypso™ mango from six trees at Bundaberg (ten fruit assessed in each of the nine canopy locations on each tree).

	Canopy location		
Aspect	Upper outside	Lower outside	Inner canopy
% DM			
North	15.5	14.9	
East	15.6	15.3	
South	15.6	15.1	
West	15.5	15.0	
			14.1
Flesh colour			
North	7.1	7.1	
East	7.3	7.5	
South	7.3	6.9	
West	7.0	6.8	
			5.75

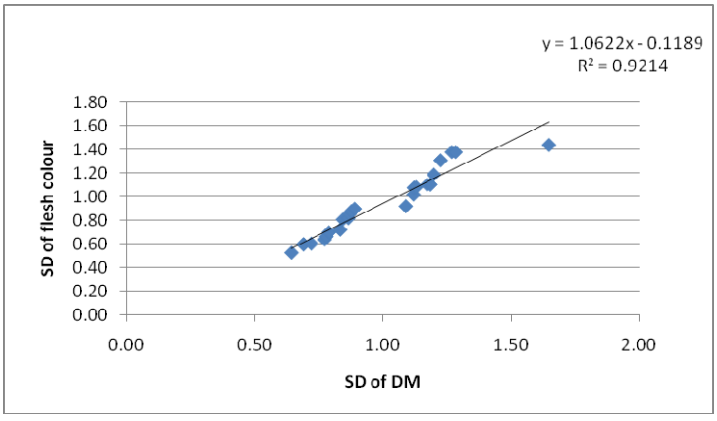


Figure 31 Relationship between SD of DM and SD of flesh colour of Calypso™ mango in Oolloo farm Bundaberg 2008 (population 18).

Assessing block or maturity zone fruit maturity

The average predicted % DM and flesh colour on selected trees within a part of the Musketeer block at the Darwin farm was relatively lower in the centre compared with the outer areas of the block, with similar patterns for both parameters (Figure 32). Within the block, the % DM ranged from 14.7 to 17.9%. This represents up to three weeks difference in maturity, and indicates the potential for early harvesting of these trees.

Fruit % DM and flesh colour also varied between trees at the Bundaberg site (Figure 33). The patterns obtained with these parameters were less similar than that obtained in Darwin, but still identified areas of the blocks that were likely to have higher maturity.

To estimate the number of trees required to accurately estimate the maturity of a given area, the combined data from blocks 3, 19 and 21 at the Bundaberg site was employed, using the average NIRS estimated % DM and flesh colour from 10 fruit from mid-height on the eastern side of each tree. The SD on average flesh colour of 10 fruit per tree across the 100 trees in these blocks was 0.34 colour units.

Using eqn. 1 (above), if a measurement uncertainty of 0.5 colour units is required, then only two trees are required to be sampled to estimate the average flesh colour for the blocks. This low sampling number is a function of the relatively small SD on flesh colour across the trees in this particular block, in comparison to that between fruit on a given tree.

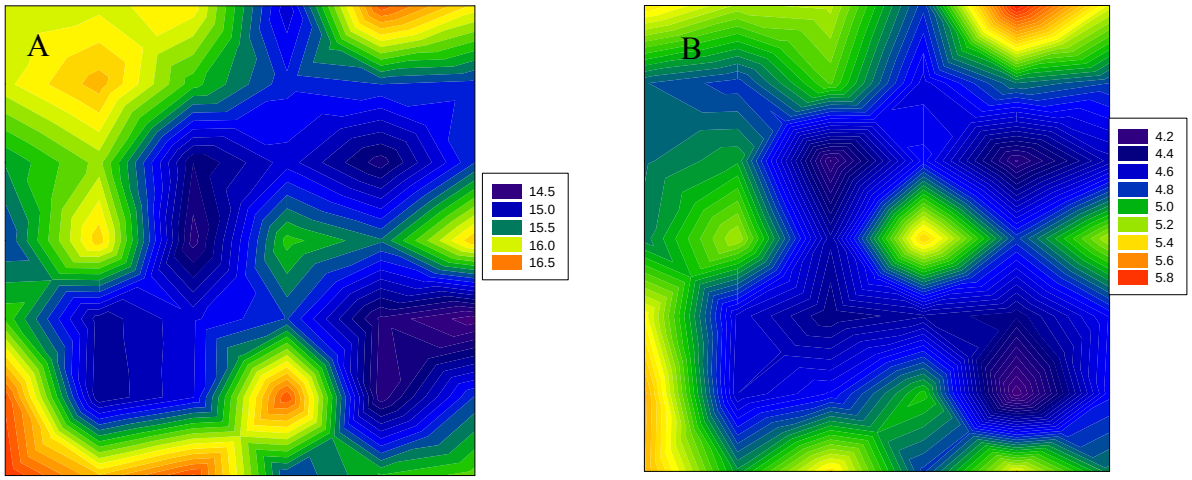


Figure 32 Contour plot of the % DM (A) and flesh colour (B) in the Musketeer block at Acacia Hills Farm. Tree number within the row is in horizontal direction and row number in the vertical direction.

Required sampling intensity is a function of variability in % DM and flesh colour within and between trees. More trees will need to be sampled if there is greater maturity variation across the block. To provide a more robust recommendation for most situations, we suggest sampling about 10% of the trees in the maturity zone, randomly selected from across the zone, and measuring 10 fruit from a designated region of the tree.

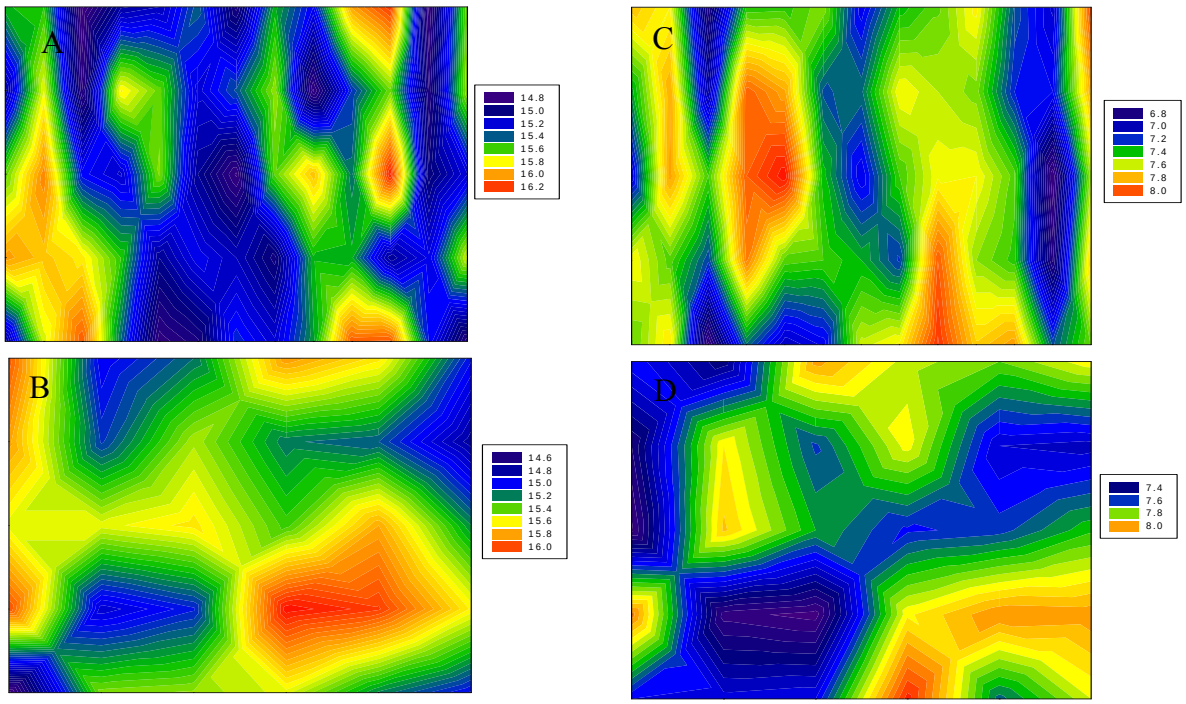


Figure 33 Contour plot of NIR predicted % DM (A and B) and flesh colour (C and D) of fruit on every fifth tree within each row, for blocks 21 and 19 (A and C), and block 3 (B and D) at Oolloo Farms Bundaberg.

Flowering date gives the first indicator of potential variations in fruit maturity across the block/farm. This should be used to identify "maturity zones" across the farm, such as early flowering, mid flowering and late flowering zones. (These are likely to be different from the farm "management" blocks). Maturity zones can be based on either individual trees or groups of trees flowering at different times. Where the flowering dates for individual trees are recorded, we suggest that:

- trees where the whole canopy has flowered be marked for strip picking, and
- trees were only a portion of the canopy has flowered (for example 30-50% of the tree had flowered early) be marked for select picking based on fruit external appearance. It is likely that where one part of the canopy flowered significantly earlier than the remainder of the canopy, that there is sufficient difference in fruit appearance at early harvest to allow distinction between the mature and immature fruit.

Trees in each maturity zone could be marked by colour-coded paint on the trunk, or similar.

Using maturity zones may enable fewer trees to be sampled with NIRS to accurately determine maturity zone maturity because of less fruit maturity variation between trees.

Changes during fruit growth

Flesh colour and % DM was repetitively estimated for 30 fruit over the last 10 days before commercial harvest. Average flesh colour and % DM increased over this period (Figure 34). The results represent an increase of 1.05 % DM and 1.27 colour units per week. This increase per week in % DM is greater than that noted over the last four years for Bundaberg, but is typical for flesh colour. The 10 day measurement period was relatively short, but still indicates that NIRS can be used to monitor changes in % DM and flesh colour as the fruit mature, and can help predict the start of harvest using these parameters.

We suggest tagging of about 10 fruit per tree on eight trees per management area and assessing every week from 4-6 weeks before the expected start of harvest. Graphing the results will help predict the start of commercial harvest for each maturity zone.

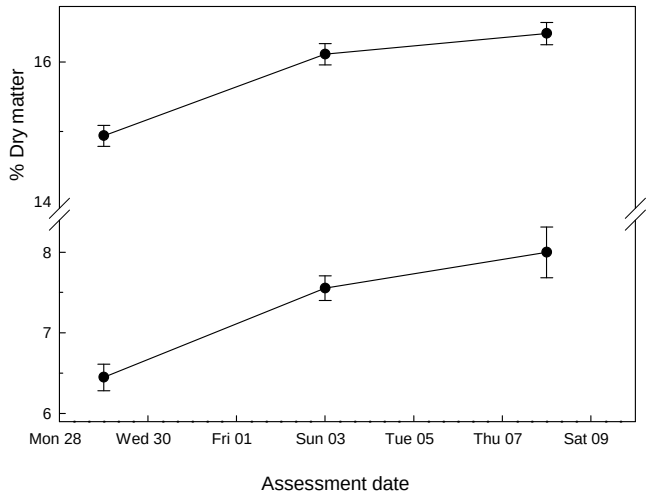


Figure 34 On-tree NIR predicted % DM and flesh colour over time, averaged over the same 30 fruit one the one tree at Bundaberg.

5.1.3.4. Conclusions and recommendations

- The NIRS handgun was very reliable throughout the season. Predictability was similar to an in-line unit. The handgun was not affected by fruit/handgun/ambient temperatures or ambient light under Northern Territory conditions.
- Using seven populations from the Northern Territory, North Queensland and southeast Queensland, it appeared that the same dry matter prediction model can be used for these populations. However, separate models were required for flesh colour.
- Commercial picking teams were not able to adequately identify the more mature fruit on the tree during early season picks. This resulted in a significant proportion of immature fruit being harvested.
- There were some differences in dry matter and flesh colour between fruit from different parts of the canopy, but often these differences were fairly small (less than 0.5% DM units). In southeast Queensland, the biggest differences were inside fruit having lower dry matter than outside fruit, and in the Northern Territory and southeast Queensland, fruit from the lower canopy having lower dry matter than fruit from other parts of the canopy, especially on the northern aspect.
- Preliminary results indicate that the handgun is useful for mapping maturity across blocks/orchards, and helping identify maturity zones for harvesting.
- Preliminary results also indicated that NIRS can predict Brix of the ripe fruit from readings taken at harvest, but further work is required. It may also provide some prediction of ripening time (possibly through % DM). Further results analysis is investigating the potential for NIRS to predict external quality of ripe fruit (rots, lenticel spotting etc).

Based on the above, the handgun is now suitable for commercial apoption. While the results this season suggest that one dry matter model can be used for all districts, we suggest that a new dry matter model be developed very early in the Darwin season, and compared with the 2007/8 model to identify season effects. The accuracy of that model in predicting dry matter and flesh colour in fruit from other farms should then be examined. If required, the information gathered during these confirmations can be used to update the model.

Growers should be encouraged to use a "maturity zone" concept for determining harvesting schedules. Maturity zones can be predicted in the first instance using flowering date data, and these zones tested for fruit maturity using the handgun. Predicting flesh colour of 10 fruit per tree on about 10% of the trees in the zone, will estimate the flesh colour of the maturity zone to within 0.5 % DM units.

Sorting of fruit in the packhouse for dry matter would be a further step in improving flavour uniformity, but should be considered secondary to better identifying fruit maturity and maturity zones.

5.2. More even maturity

5.2.1. Manipulation of flowering time of Calypso™ mango with gibberellic acid

5.2.1.1. Introduction

Flowering of Calypso™ mango is relatively easily triggered compared with other cultivars however this phenological event is usually drawn out as shoot tips on trees are at different stages of physiological maturity as they approach the cooler induction months of winter. In most years this leads to a prolonged flowering period which in turn can result in mixed fruit maturity at harvest. It is well documented that foliar applications of Gibberellic acid (GA) made strategically in the autumn and early winter will prevent flowering in mango (Chacko *et al*. 1976; Turnbull *et al*. 1996) due to the maintenance of high endogenous concentrations in vegetative terminals that become floral when exposed to low (≤ 12°C) minimum temperatures. To maintain shoots in a vegetative condition foliar GA applications must be made at intervals less than 6 weeks apart during the floral induction period. The objective of this study was to delay the early onset of flowering in the most physiologically advanced shoots thus allowing late-maturing shoots to catch up so that when the tree was released from the effect of the GA treatment a uniform flowering would occur. The research was carried out over the 2007/08 and 2008/09 fruiting seasons and the results are reported below.

5.2.1.2. Materials and methods

Calypso™ trees grafted to seedling 'Kensington Pride' rootstocks growing at Bundaberg were used for this experiment. Trees selected in 2007/08 were in their seventh year of cropping while in 2008/09 younger trees in their fourth year of cropping were used. General agronomic practices for managing the crop were as described in the Calypso™ Best Practice Guide (Whiley and Hofman, 2006). The experimental design in both years was a 5 x 5 randomised block with single tree plots with the source of GA being the commercial product Progibb GA® (100 g/L, Valent BioSciences, Australia). Treatments were applied to the trees using a Stihl motorised knapsack spray unit. Agral®, a commercial surfactant at 0.1% concentration was added to the tank mix as per recommendations for the use of Progibb GA®. Treatments for each year of the experiment are detailed below:

<u>2007/08</u>

1. Control (nil application)
2. GA sprayed at 40 $mg.kg^{-1}$ once at autumn flush maturity (AFM) (18/05/2007)
3. GA sprayed at 40 $mg.kg^{-1}$ once at AFM and then repeated 5 weeks later
4. GA sprayed at 40 $mg.kg^{-1}$ once at AFM and then repeated 5 & 10 weeks later
5. GA sprayed at 40 $mg.kg^{-1}$ once at AFM and then repeated 5, 10 & 15 weeks later

The first GA spray application was on the 18th May, the second the 24th June, the third the 19th July 2007 and the fourth the 28th August 2007.

<u>2008/09</u>

1. Control (nil application)
2. GA sprayed at 20 $mg.kg^{-1}$ at AFM (10/05/2008)
3. GA sprayed at 20 $mg.kg^{-1}$ once at AFM and then repeated 5 weeks later
4. GA sprayed at 30 $mg.kg^{-1}$ once at AFM (10/05/2008)
5. GA sprayed at 30 $mg.kg^{-1}$ at AFM and then repeated 5 weeks later

The first GA spray application was on the 10th May and the second the 14th June.

Flowering intensity was progressively measured on a 0-5 scale where 0 = nil flowering and 5 = 100% of terminals flowering (Plate 8). Trees were harvested at fruit maturity and the yield recorded.

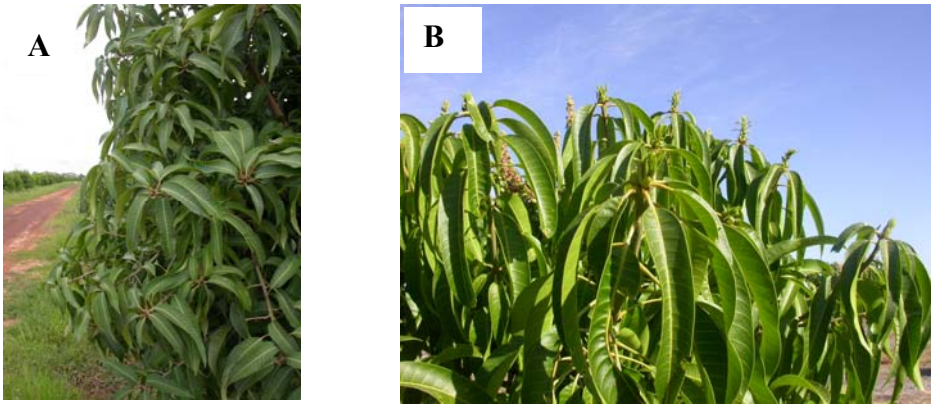


Plate 8 Flowering rating (0-5) in Calypso™ following applications of Progibb GA®. 0 = nil flowering depicted in A and 5 = 100% flowering depicted in B.

Data were analysed by ANOVA and tested at $P \leq 0.05$.

5.2.1.3. Results and discussion

2007/08

In all cases the application of Gibberellic acid reduced flowering intensity when compared with the control trees which reached 100% of terminals flowering (5) by the 1st October 2007 (Table 1). At this time there was evidence of fruit set on some inflorescences and the intensity of flowering did not improve in any treatments past this point (data not presented). For the most part flowering was progressively less as the number of GA applications to trees increased. All GA treatments reduced crop yield which is a direct result of the reduction in flowering intensity (Table 44).

Table 44 Effect of Gibberellic acid sprays on flowering intensity of Calypso™ mango growing in the subtropics of Queensland during the 2007/08 fruiting season. Flowering intensity was measured on a 0-5 scale where 0 = nil terminals flowering and 5 = 100% of terminals flowering. Values in columns with different letters are significantly different at $P \leq 0.05$ as tested by ANOVA.

Treatments	**%age flowering intensity of shoots**			**Yield**
	28/08/07	**12/09/07**	**1/10/07**	**t/ha**
Control	4.4[a]	4.4[a]	5.0[a]	18.2[a]
GA at 40 mg.kg^{-1} at AFM	1.6[b]	2.8[b]	3.2[b]	15.4[b]
GA at 40 mg.kg^{-1} at AFM + 5 weeks	0.4[c]	2.0[b]	1.8[c]	12.1[b]
GA at 40 mg.kg^{-1} at AFM + 5 and 10 weeks later	0.8[c]	2.2[b]	2.4[b]	14.7[b]
GA at 40 mg.kg^{-1} at AFM + 5, 10 and 15 weeks later	0.2[c]	1.2[c]	1.6[c]	13.3[b]
LSD ($P \leq 0.05$)	**1.2**	**0.9**	**0.7**	**2.7**

2008/09

Flower development on the trees was later than in 2007/08 and this is likely due to the very mild winter temperatures experienced in this region. Many of the older trees in the orchard did not flower at all in 2008 indicating that floral induction conditions were not reached prior to warming

conditions in spring. In the 2008/09 fruiting season untreated trees in the experiment never achieved 100% of terminal flowering but instead scored 4.8 out of the possible 5.0 for full flower expression (Table 45). Both GA treatments at either 20 or 30 mg.kg^{-1} with either one or two sprays significantly reduced flowering intensity with respect to the control trees and this was reflect in a significantly lower fruit yield. Due to the negative impact on yield from the GA treatments uniformity of fruit maturity was not assessed.

Table 45 Effect of Gibberellic acid sprays on flowering intensity of Calypso^{TM} mango growing in the subtropics of Queensland during the 2008/09 fruiting season. Flowering intensity was measured on a 0-5 scale where 0 = nil terminals flowering and 5 = 100% of terminals flowering. Values in columns with different letters are significantly different at $P \leq 0.05$ as tested by ANOVA.

Treatments	**%age flowering intensity of shoots**			**Yield**
	25/08/08	**13/09/08**	**29/09/08**	**t/ha**
Control	0.8	3.2	4.7^{a}	8.2^{a}
GA at 20 mg.kg^{-1} at AFM	0.7	3.8	4.0^{b}	6.4^{ab}
GA at 20 mg.kg^{-1} at AFM + 5 weeks	0.4	1.6	2.4^{c}	3.1^{c}
GA at 30 mg.kg^{-1} at AFM	0.9	3.3	3.5^{b}	4.9^{bc}
GA at 30 mg.kg^{-1} at AFM + 5 weeks	0.2	1.2	2.0^{c}	2.3^{c}
LSD ($P \leq 0.05$)	**ns**	**ns**	**0.6**	**2.7**

The experiment has confirmed that Calypso^{TM} mango trees are responsive to foliar applications of GA which is similar to the findings of Chacko *et al*. 1976 and Turnbull *et al*. 1996 for other mango cultivars. However, all GA applications over both fruiting seasons studied reduced flowering intensity and fruit yield giving an unacceptable commercial result. Winter temperatures during 2007 were particularly low with some frost damage to mango trees growing in low-lying pockets throughout the orchard. Additionally, the period of low temperatures was extended when compared with average temperature data for this area (BOM). This produced a very strong induction event for trees which had very uniform natural flowering with greater synchrony than seen in other years demonstrated by the high flowering intensity measured in control trees (5.0) at the completion of flowering (Table 44).

In the winter of 2008 the occurrence of strong induction temperatures (≤ 12°C) was delayed until the latter part of July and then only occurred over a few nights (BOM). Despite the lower concentration of GA applied and the fewer application times compared to 2007 the 2008 treatments overall reduced flowering intensity and yield similar to 2007/08 (Table 45).

The expectation from this research was that GA-treated trees compared with controls would have greater uniformity in floral bud break that should be seen in the last three weeks of flowering. However, the 2007/08 data shows that the reverse happened due to a stronger than normal temperature induction period and the likelihood that GA at 40 mg.kg-1 was too strong for use on Calypso^{TM}trees since even one application reduced flowering intensity (Table 44). Data from 2008/09 indicates that there was potential for greater uniformity of flowering since there was trend (not significant) for treatments with a single application of GA to have greater floral expression two weeks out from the completion of flowering than untreated trees. However, even the reduced concentrations of GA used this year under the floral induction conditions received appear too high and overall reduced total floral expression and yield. The work of Chacko *et al*. (1976) and Turnbull *et al*. (1996) used GA concentrations in excess of 50 mg.kg^{-1} with their research aimed at preventing flowering thus there is no knowledge if concentrations lower than 20 mg.kg^{-1} are biologically active on mangoes and the relationship with seasonal variation in the floral induction signal.

In conclusion from the studies over two consecutive years reported herein it appears that the interaction between GA concentration and the length of winter induction temperatures (which are not predictable at the time treatments are applied) is too finely balance to produce a predictable and commercially useful result.

5.3. Flesh changes during ripening

5.3.1. Introduction

Significant changes occur within the flesh of ripening mangoes, which result in the flesh becoming edible. These changes involve softening and a degradation of starches to sugars, and a decline in acidity. Previous work has suggested that less mature fruit take longer to develop acceptable flavour, and that flavour can deteriorate if the fruit are held too long. It is unclear what roles sugars and acids play in the development and loss of flavour, and whether the interaction between sugars, acidity and flavour change as fruit mature.

This small trial recorded the changes in the external and internal characteristics of Calypso™ mango fruit during normal ripening. The trial was repeated with fruit from the same orchard, harvested at early and late maturity. An iodine spray on the cut surface of the fruit to measure starch levels, was also tested as an indicator of ripeness.

5.3.2. Materials and methods

5.3.2.1. Fruit

Calypso™ mango fruit were harvested at two stages of maturity from the same trees at Oolloo Farms, Bundaberg:

- early harvest (23/1/2007): flesh colour of 6.6; dry matter of 15.7%, Brix of 8.1
- late harvest (14/2/2007): flesh colour of 9.8; dry matter of 15.7, Brix of 7.9

The fruit were taken to the laboratory at the Maroochy Research Station within four hours of harvest, immediately treated with 10 ppm ethylene for two days at 20°C, then held at 20°C for ripening.

Every 1-2 days after harvest, three trays (10-12 fruit each) were removed, and the 1-2 least ripe and most of ripe fruit were removed. The remaining fruit were divided into three groups (containing 9-10 fruit each) based on fruit firmness and skin colour. These represented three replications for statistical purposes.

5.3.2.2. Quality assessment

Fruit firmness was assessed using hand firmness (0 =firm, 3=eating soft for Calypso™, 4=very soft), and the Aweta Acoustic Firmness Tester. The Aweta unit is based on the analysis of the resonance frequencies produced when the fruit surface is tapped. It is a non-destructive and rapid assessment of firmness. The usefulness of this unit for rapidly assessing Calypso™ firmness is currently being evaluated.

The fruit were assessed for background skin colour using the following scale: 1=0-10% yellow, 2=10-30% yellow, 3=30-50% yellow, 4=50-70% yellow, 5=70-90% yellow, and 6=90-100% yellow. The rating refers to the percentage of the background skin colour area showing yellow.

For the fruit in each replication, one cheek from each fruit was removed, the flesh diced and combined with the other fruit in the same replication to provide one composite sample per replication. A sample was presented to 4-5 trained staff from the postharvest unit at MRS for flavour assessment using a 1-9 rating scale (1=dislike extremely; 9=like extremely). Flavour was assessed from day six only, to reduce taste panel fatigue. An additional sample was frozen for Brix and acidity measurement. Titratable acidity was determined using a Metrohm

Titrino autotitrater and the results expressed as % citric acid. Brix was measured with an Atago bench refractometer with temperature compensation.

5.3.2.3. Iodine test

Iodine solution (made of 10 g of potassium iodide dissolved in 1 L of distilled water, with the addition of 2.5 of iodine crystals) was sprayed on the cut surface of the cheek with the seed. After 1-2 minutes, the colour reaction was visually rated as the percentage of surface area stained by the solution.

5.3.2.4. Statistical analysis

The results were analysed as a factorial experiment, with harvest date and days after harvest as treatments. Replication was achieved by dividing the fruit at each assessment time into three groups based on the stage of ripeness as indicated by skin colour and firmness.

5.3.3. Results

The fruit softened rapidly over the first 6-7 days (Figure 35). There was little difference in softening patterns between the early and late season fruit until about 10 days after harvest, after which the early season fruit changed little, but the late season fruit continued to soften slowly.

Firmness as measured by the Aweta unit showed a similar pattern to hand firmness (decreasing values indicate softer fruit). With the Aweta, the later harvest fruit were firmer in the early stages, but there was little consistent difference between the maturity after about six days.

Skin colour scores increased rapidly until about six days after harvest. The late harvest fruit reached full colour by six days after harvest, but the early harvest fruit required an additional four days to reach full colour.

Flavour of the late harvest fruit was higher in most cases than in early harvest fruit (Figure 36). With the early harvest fruit, flavour was still unacceptable six days after harvest, but increased over the next day to a flavour rating of six or above. In contrast, flavour in the late harvest fruit was very acceptable by day six.

Brix levels were always higher in the late harvest fruit (except for day one). Brix increased rapidly until day six after harvest but changed little thereafter in both the early and late harvest fruit.

Acidity decreased rapidly until about day eight. In the early season fruit, acidity was higher than the late season fruit up till day five, then was slightly lower than late season fruit until about day nine.

It appears the main reason for the lower flavour in early harvest fruit at day six was lower Brix, since acidity levels in both early and late harvest fruit were similar. The main reason for the increased flavour in the early season fruit between days six and seven was decreasing acidity, rather than increasing Brix (increasing volatiles may also have contributed to improved flavour over this time). It is likely that the higher Brix in late harvest fruit "masks" potential negative effects of high acidity on flavour in the less ripe fruit. In early season fruit this is less likely, so that flavour is more dependent on acidity decrease during ripening.

Can Brix, acidity or skin colour be used as an indicator for ripener dispatch?

The results suggest that Brix is not a good indicator of when the fruit reach acceptable flavour, since in the early harvest fruit, Brix changed little after day six even though flavour improved by the next day. Acidity may provide a better measure, but maximum acceptable acidity may be higher for late harvest fruit because of the higher Brix (and other flavour

components). For example, 0.53% acidity was associated with a flavour rating of seven in late harvest fruit, but a maximum of 0.35% was required in the early harvest fruit.

The rate of yellow skin colour development during ripening can be affected by production and ripening conditions, but these have less influence on Calypso™ mango compared with other varieties. Under good management practices, we would expect skin colour to be an acceptable indicator of ripeness stage. The late maturity fruit had reached acceptable flavour at full yellow skin colour (day 6). In the early maturity fruit the change in skin colour from five to six was more gradual, but a skin colour rating of above about 5.5 was related to acceptable flavour. We would expect a skin colour rating of close to six to be a sufficiently reliable indicator of acceptable flavour.

These results generally confirm the findings of the "ripener" results this season.

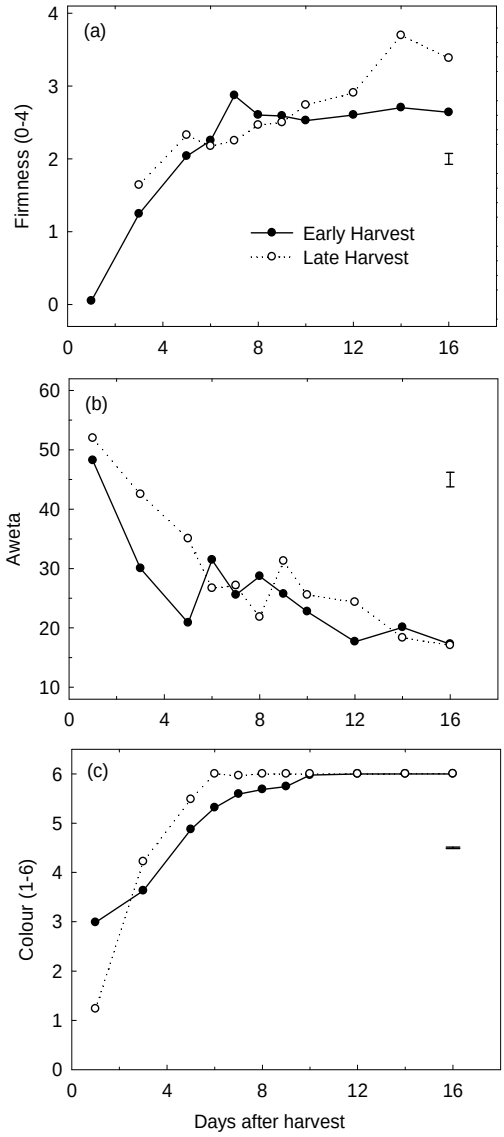


Figure 35. Changes in firmness as measured by hand (0= firm, 4= very soft) and the Aweta acoustic firmness tester (50-60=firm, approx 10= very soft) and skin colour (1=green, 6=yellow) of Calypso™ mango fruit during ripening. Fruit were sampled at early and late maturity from the same trees. The bar on each graph indicates the least significant difference ($P<0.05$). Treatment differences greater than the length of the bar indicates statistically significant treatment effects.

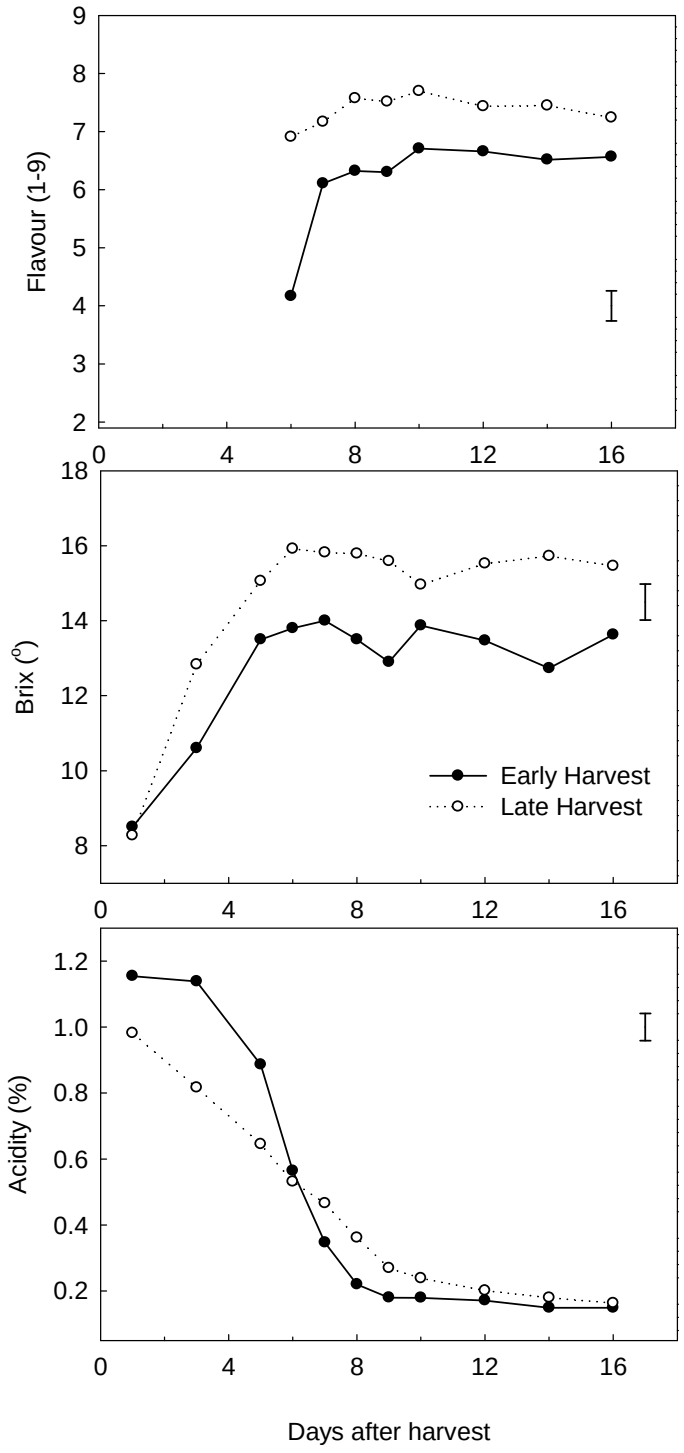


Figure 36. Changes in flavour, Brix and acidity of the flesh of Calypso™ mango fruit during ripening. Fruit were sampled at early maturity and late maturity from the same trees. The bar on each graph indicates the least significant difference ($P<0.05$). Treatment differences greater than the length of the bar indicate statistically significant treatment effects.

The iodine test suggested that starch levels started to decrease from harvest in early harvest fruit (Figure 37). The absence of detectable iodine colour change over the first two days in

late harvest fruit may be because of higher starch concentrations at harvest, requiring more time to reduce starch concentrations significantly to be detectable using the iodine test.

The results suggest that starch decreased more rapidly in the late harvest fruit compared with early harvest, so that by day nine there was little significant difference between the two harvests.

At acceptable flavour, about 40% of the cut fruit area in late harvest fruit was stained, but with early harvest fruit, about 20% of the cut area was stained. The potentially higher starch concentrations in late harvest fruit may have resulted in achieving sufficient Brix for acceptable flavour more quickly compared with early harvest fruit, and also at higher residual starch concentrations. Therefore, it may be difficult to establish a reliable starch level because of maturity effects.

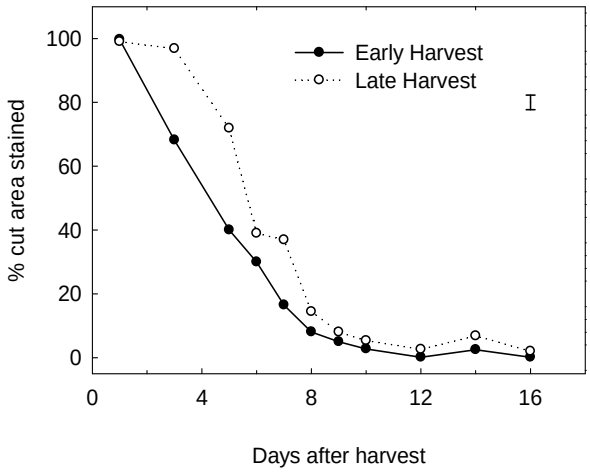


Figure 37. Changes in percentage of the cut flesh surface of Calypso™ mango stained purple after spraying with iodine solution. The fruit were harvested near the start and near the end of the commercial season, and assessed at various times after harvest. The bar on each graph indicates the least significant difference ($P<0.05$). Treatment differences greater than the length of the bar indicate statistically significant treatment effects.

5.3.4. Conclusions and recommendations

- Fruit from early and late harvests softened at similar rates.
- Late harvest fruit reached full colour by day six, but early harvest fruit required an additional three days to reach full colour.
- Early harvest fruit had unacceptable flavour by day six, whereas the flavour of late harvest fruit was very acceptable.
- Late harvest fruit had higher Brix than early harvest fruit at all stages after harvest (except day one). Also, late harvest fruit had lower acidity than late harvest fruit up to day six.
- There was little change in Brix after day six in both the early and late harvest fruit. With early harvest fruit, the flavour improved between day six and seven. During this time, there was no change in Brix, but acidity decreased rapidly. This suggests that

- It is likely that acidity is more critical in early harvest fruit, because the higher Brix in late harvest fruit may "mask" the negative effect of high acidity on flavour.
- Given the negligible change in Brix during the latter stages of ripening, we do not consider Brix a reliable estimate of when the fruit are ripe enough for dispatch from the ripener. Acidity may be a more reliable indicator, particularly in less mature fruit, but acidity is more difficult to measure.
- For both harvests, flavour was acceptable by the time the fruit had reached full yellow colour.
- Starch (as indicated by purple colour after spraying with iodine) decreased as the fruit ripened. The late harvest fruit had higher starch at acceptable flavour, compared with early harvest fruit.

On the basis of the above:

- Skin colour is likely to be a better indicator of flavour in mature, ripening fruit. This confirms the results of the ripener studies.
- Brix does not appear to be a good indicator of flavour in the near-ripe fruit because of little change in Brix during the later stages of ripening.
- Acidity is a more accurate indicator, but the levels at acceptable flavour are influenced by maturity (through Brix). A maximum acidity of about 0.35% should ensure acceptable flavour for all maturities, but a higher acidity could be tolerated in later harvest fruit.
- Acidity is more difficult to measure, and less useable as a commercial indicator of ripeness.
- An iodine spray to indicate residual starch can indicate flavour, but will be influenced by fruit maturity at harvest.
- The potential for NIRS to estimate acidity will be evaluated this season.

5.4. At what ripeness stage should fruit be dispatched from the ripener?

5.4.1. Introduction

Calypso^{TM} mango has a mild flavour. Good maturity standards and adherence helps improve flavour. The stage of ripeness at which the fruit is consumed will also affect flavour. If consumed too early, the fruit can have a "starchy", taste, low sugar and relatively high acidity. If consumed too late, the acidity and the mango volatile compounds may have declined, resulting in a bland flavour.

The stage of ripeness at which the fruit are dispatched from the ripener to the retail store can be a critical factor in the flavour of the fruit when consumed because of inadequate consumer knowledge. Therefore, guidelines are required for ripeners to ensure that fruit are ripened to the right stage before dispatch.

This trial obtained fruit at the point of dispatch from the ripener, then assessed flavour and other quality parameters the following day (when the fruit were likely to be placed on the retail shelf), and about every two days thereafter for a further six days. A total of 13 consignments were evaluated.

5.4.2. Materials and methods

5.4.2.1. Fruit

Six trays (60 fruit) of Calypso™ fruit were obtained from the commercial Calypso ripener at the Brisbane markets (Le Manna) during the Northern Territory season, and to a lesser extent the north Queensland and south-east Queensland seasons (Table 46). The fruit were transported to the DPI&F laboratory at Maroochy Research Station (MRS) at Nambour the same day and held at 20°C. The following day (in most cases), when the fruit were likely to be delivered to the retail store, 15 fruit were assessed for external appearance (firmness, flesh colour flavour, Brix and acidity). Additional fruit were evaluated about every two days for the next 6-8 days.

Table 46. Details of fruit consignment used in the study

Batch	Date received	Grower	Pallet No	Batch	Pack date	Comments
1	25 Oct	Acacia Hills	76058	18245	14 Oct	
2	31 Oct	Acacia Hills	76223	18280	19 Oct	
3	7 Nov	Acacia Hills	76411	18321	26 Oct	
4	14 Nov	PAL Investments packed by Acacia Farms		18329	27 Oct	
5	21 Nov	Oolloo Farms packed by Pinata			4 Nov	
6	28 Nov	Oolloo Farms packed by Pinata	2090		19 Nov	Arrived La Manna 23/11, 2 days 18°C + eth, 1 day 18°C, 3 days at 13°C.
7	5 Dec	Grower 402396 - packed by Pinata			27 Nov	Not full colour on arrival
8	12 Dec	Oolloo Farms	7461	531A		Dark spots in the flesh
9	28 Dec	Tinmarl Pty Ltd.		Q3360	21 Dec	Not full colour on arrival
10	4 Jan	Gilbert Gold			17 Dec	
11	18 Jan	Blushing acres			9 Jan	Not full colour on arrival
12	2 Feb	Kiamia Pty Ltd			3 Jan	
13	16 Feb	Sunny Bluff			6 Feb	Fruit at full colour

5.4.2.2. Quality assesssment

External appearance was assessed on every fruit in each tray using the rating systems in Table 47.

Table 47. Rating systems for fruit firmness, lenticel spotting, skin browning, and rots of Calypso™ mango.

Rating	Hand firmness	Area of the skin affected		
		Lenticel spotting	Skin browning	All rots
0	Hard	Nil	Nil	Nil
1	Rubbery	To 10%	To 3cm2	To 3cm2
2	Sprung	To 25%	To 6 cm2	To 6 cm2
3	Soft	To 50%	To 25%	To 25%
4	Very soft	> 50%	> 25%	> 25%

The fruit were assessed for background skin colour using the following scale: 1=0-10% yellow, 2=10-30% yellow, 3=30-50% yellow, 4=50-70% yellow, 5=70-90% yellow, and 6=90-100% yellow. The rating refers to the percentage of the background skin colour area showing yellow. The rots were identified based on the location of the rot on the fruit, rather than identifying the fungi from the affected area. The flesh colour was measured about midway between the skin and the seed using a Minolta colour meter. The results are presented as Hue angle, with lower values indicating a more yellow colour.

Fruit were assessed as having lost saleability at a rating of 1 or higher for rots, a rating of 3 or higher for lenticel spotting or skin browning, or if the combined rating for any two of these skin defects was 3 or more.

The flavour of the flesh was determined using 8-10 typical fruit of similar firmness (ripeness stage) for each assessment day. One cheek from each fruit was removed, the flesh diced and

combined with the other fruit to provide one composite sample. A sample was presented to about 16 staff at MRS for flavour assessment using a 1-9 rating scale (1=dislike extremely; 9=like extremely). Samples from the same batch were evaluated by each taster on three occasions during the day to account for variability in the assessment over time. An additional sample was frozen for Brix and acidity measurement (three sub-samples per batch per sample time). Titratable acidity was determined using a Metrohm Titrino autotitrater and the results expressed as % citric acid. Brix was measured with an Atago refractometer with temperature compensation.

5.5. Results and discussion

5.5.1. Flavour, skin colour, firmness, flesh colour

Roughly half of the consignments had unacceptable favour one day after dispatch from the ripener (consignments 1, 2, 5, 7, 9 and 11; Figure 38). However, in these consignments flavour rapidly improved so that in most cases flavour was above the 5.5 benchmark within one day (or two days after dispatch from the ripener). Only in the first consignment did flavour take longer to reach a 5.5 rating. There was little decrease in flavour with increasing days after dispatch. However, observations suggested that the texture was less acceptable (the flesh were softer and more "slimy").

Only four consignments did not have full colour on arrival (Figure 38), but all of them (except consignment 9) reached full colour within two days. This suggests a close relationship between unacceptable flavour, and fruit not having reached full colour. In only one instance (consignment 1) the fruit were at full skin colour, but with unacceptable flavour.

Most consignments were close to the expected firmness of three (soft) on arrival. Again, the consignments with unacceptable flavour were generally firmer, although there were some firm consignments that had acceptable flavour (e.g. two and 10).

The flesh colour became more yellow with longer holding times (Figure 38). Consignments one and two had significantly less yellow flesh colour and these also had unacceptable flavour on arrival. These consignments may have been less mature. Figure 39 also confirms that skin colour is a good indicator of fruit that have not reached acceptable flavour (the yellow area). The samples with unacceptable flavour (below a rating of 5.5) had skin colours ranging from 5.7 to almost 6, although most of the samples had acceptable flavour at a skin colour rating of 5.9 or more (effectively no green skin colour on any fruit in the tray; see Plate 9).

Fruit firmness was not as good an indicator of acceptable flavour as skin colour. Dispatching when all fruit had reached a firmness of three (considered as the stage at which Calypso fruit should be consumed) would ensure acceptable flavour of all consignments, but a significant number of consignments had reached acceptable flavour at firmness less than three.

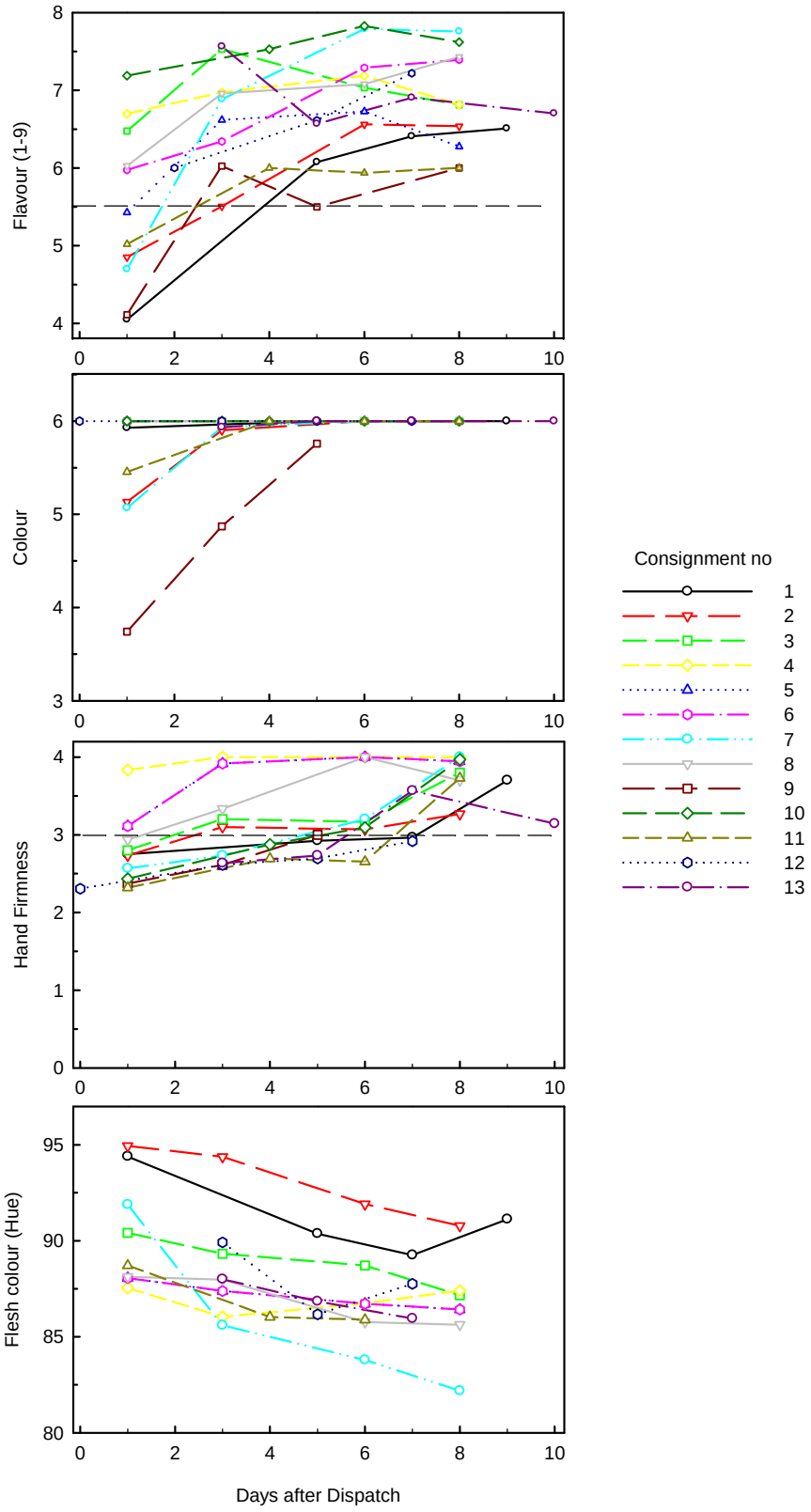


Figure 38 Flavour (1-9), skin colour (1-6) firmness (0-4) and flesh colour (hue angle; lower values indicate more yellow colour) of the flesh of commercially ripened Calypso™ mangoes at different times after dispatch form the ripener. The results are from 13 different consignments (combination of different regions and harvest dates). Each data point represents the means of 10-14 fruit.

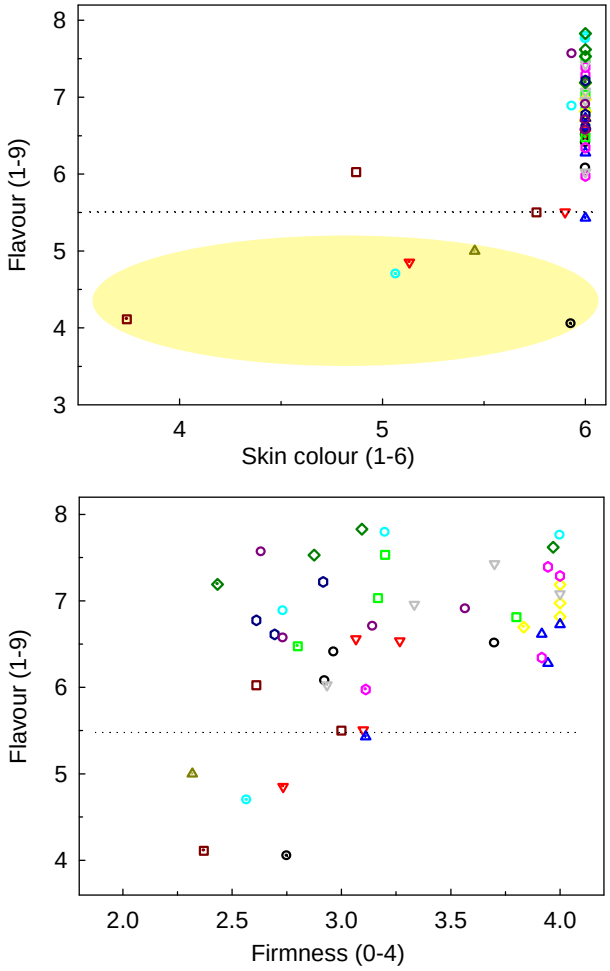


Figure 39 The relationship between flavour (1-9), and skin colour (1-6) or firmness (0-4) of commercially ripened Calypso™ mangoes from 13 different consignments from several regions and harvest times. Fruit were assessed 3-5 times for about 10 days after dispatch from the ripener. Each data point represents the mean of 10-14 fruit per consignment and days after dispatch. The filled symbols represent the results for each consignment one day after dispatch, and the open symbols are from three days after dispatch. The shaded area are those consignments that had unacceptable flavour.

The Brix ranged from 12-18° between consignments (Figure 40). There was little change in Brix as the fruit aged for any of the consignments. In most consignments, acidity decreased significantly with days from dispatch, particularly in the early stages.

In relation to flavour, consignments 1, 2, 5, 7, 9 and 11 had unacceptable flavour one day after dispatch. Of these, consignments 1, 2, 5 and 9 had the lowest Brix levels of all consignments. Consignments 1 and 9 also had very high acidity. Consignment 7 had high Brix, but also very high acidity one day after dispatch, and consignment 11 had average Brix but relatively high acidity. Therefore, it appears that poor flavour was determined by either low Brix and/or high acidity.

Previous years results suggested that acidity plays a greater role in flavour when Brix is low. This is more likely to occur in early-season fruit, so in these fruit there is a smaller window of acceptable flavour when either the acidity is too high (unripe) or the acidity too low and the fruit becomes bland (overripe). In more mature fruit, the higher Brix more effectively masks the impact of acidity on flavour.

It is interesting to note that consignment 10 fruit (Gilbert Gold) had one of the highest flavours, and also the highest Brix. Fruit from this orchard has been consistently reported as having exceptional flavour over several years.

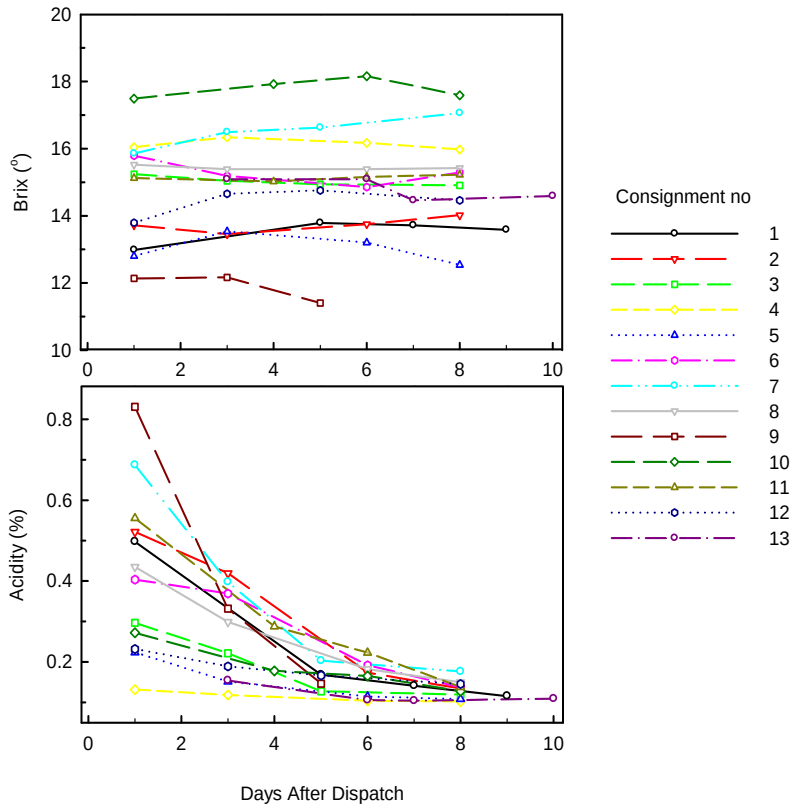


Figure 40 Brix (o) and acidity (%) of the flesh of commercially ripened Calypso mangoes from 13 different consignments (regions and harvest times) as affected by time after dispatch (days). Each data point represents the means of 10-14 fruit.

Figure 41 suggests the following:

- Brix, acidity and the Brix/acidity ratio influence flavour.
- Of the three, acidity had the strongest relationship (highest r^2 value) with flavour.
- In relation to Brix, those samples with unacceptable flavour (consignments 1, 2, 7, 9 and 11 at one day after dispatch) did not necessarily have the lowest Brix.
- By contrast, these samples had the highest acidity.
- These samples also had the lowest Brix/acidity ratio, mainly because of the higher acidity, rather than lower Brix.

These observations again confirm that, in relation to ripening Calypso™ fruit, fruit acidity plays a larger role in determining when the fruit ripe enough to eat, than does Brix.

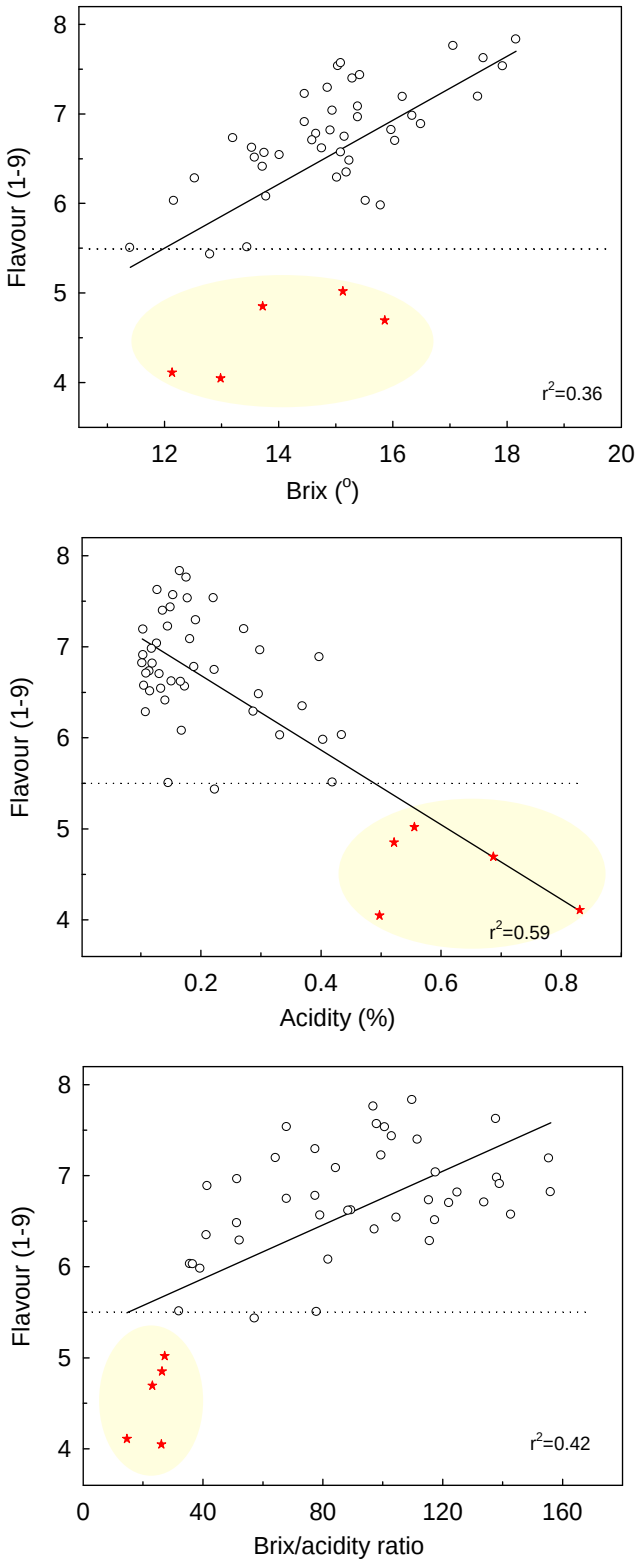


Figure 41 The relationship between flavour (1-9), and Brix (o)acidity (%) and the Brix/acidity ratio of commercially ripened Calypso™ mangoes from 13 different consignments from several regions and harvest times. Fruit were assessed 3-5 times for about 10 days after dispatch from the ripener. Each data point represents the mean of 10-14 fruit per consignment and days after dispatch. The red, star data points represent one day after dispatch for consignments 1, 2, 7, 9 and 11, all of which had unacceptable flavour. The shaded areas are those consignments that had unacceptable flavour.

5.5.2. External appearance and saleability

In six of the samples lenticel spotting increased with time (Figure 42, and Plate 10). The strong correlation between lenticel spotting and loss of saleability confirms that lenticel spotting was the major factor in loss of saleability. This confirms previous observations that ageing fruit often have more lenticel spotting.

There was little relationship between rots and saleable life (data not presented).

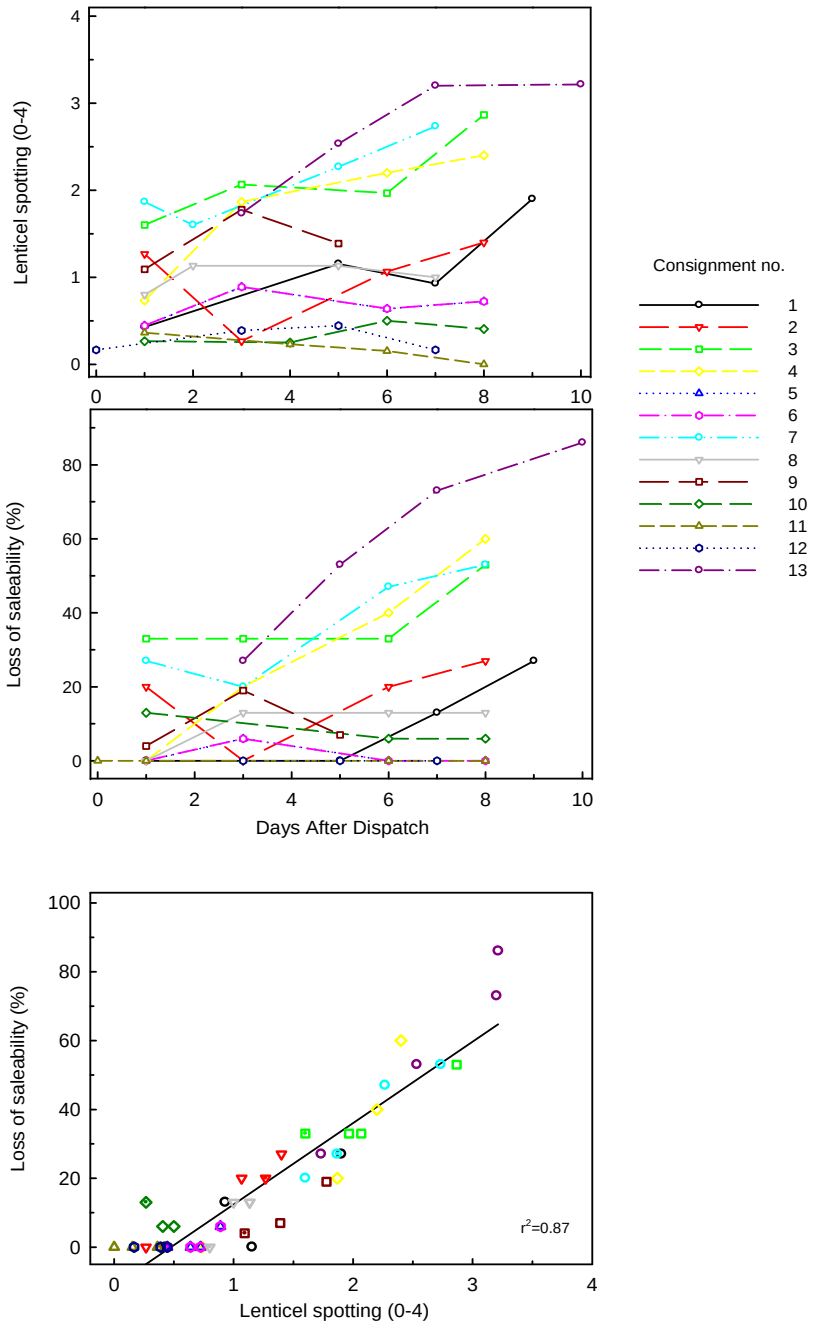


Figure 42 The severity of lenticel spotting (0-4) and the loss in saleability for 13 consignments of Calypso™ mango at different times (days) after dispatch (days). Also, the relationship between lenticel spotting and the loss of saleability of commercially ripened Calypso mangoes from the 13 consignments and different times after dispatch. Each data point represents the means of 10-14 fruit. The filled symbols are those at one day after dispatch for each consignment.

Consignment 11 on arrival at the laboratory (one day after dispatch from the ripener). Colour rating of 5.5 (about 90% yellow skin colour). These fruit had unacceptable flavour. We consider the fruit were dispatched too early based on our recommendation of dispatching at full yellow colour (rating six).

Consignment 11 one day after arrival at the laboratory (two days after dispatch from the ripener). Colour rating of 6.0 (about 100% yellow skin colour), and acceptable flavour.

Plate 9. Calypso™ mango fruit from consignment 11. One day after dispatch from the ripener, the fruit had a colour rating of 5.5 (about 90% yellow colour) but two days after dispatch, the skin colour rating was six (100% yellow colour).

One day after dispatch

3

Five days after dispatch

Plate 10. Calypso™ mango fruit from consignment 13, at one, five, seven and nine days after dispatch from the ripener. Fruit were dispatched at the right stage of skin colour (full yellow; colour ratings six). Note the increase in lenticel spotting as the fruit aged.

5.5.3. Conclusions and recommendations

- There is considerable variation between fruit consignments. Therefore, useable recommendations should be expected to be applicable to the majority (say 95%), rather than all consignments.
- A recommendation that all fruit should have **just** reached full colour on dispatch would minimise the risk of unripe fruit at retail level. However, in some dispatches skin colour will not be a reliable indicator of flavour, for example fruit from high nitrogen or top-worked trees.
- A fruit firmness of three (ready to eat) would minimise the risk of poor flavour fruit being offered to the consumer, but a large number of samples had acceptable flavour at firmness 2.5. Also, it is more difficult to "train" assessors in firmness measures.
- The results suggest that most fruit that are fully coloured will have acceptable flavour, although leaving them for several days longer can improve flavour.
- There will large differences in Brix between consignments (a range of 12-18°), but there was no change in Brix on receival and over the next 6-8 days.
- In most consignments, acidity decreased rapidly in the first 1-3 days after receival.
- Consignments with low flavour on receival had relatively low Brix and/or high acidity. Flavour generally improved soon after dispatch because of decreasing acidity after 1-2 days.
- There is a risk of increased lenticel spotting and loss of texture (observational data) if the fruit are not sold quickly

6. Improving external quality

6.1. Improving harvesting and packing practices

6.1.1. Harvest aid performance

Several harvest aid systems were evaluated. The detailed results are confidential, but a general summary of the recommendations are presented in the Executive Summary

6.1.2. Transport of fruit in field bins to a central packing facility

6.1.2.1. Introduction

The effect on quality of transporting Calypso™ mango fruit harvested in Katherine, NT in field bins for distances of 30-200 km from the field to the packing shed was investigated.

Fruit were harvested using standard commercial practice (harvest aids). In the first trial (early harvest), fruit were placed directly into 350 kg plastic field bins, lined (both bottom and sides) with plastic or 1½ corrugated cardboard, or no lining. In the second trial (late harvest), fruit were placed into 450 kg plastic field bins, lined (only bottom) with 1½ corrugated cardboard, or thin corrugated cardboard, or no lining. Fruit from both trials were transported from the farm to a packhouse about 30 km away, or to one about 200 km distant, using air suspension trucks. Fruit were then rated for transport damage on arrival at both locations. Fruit samples were taken from each bin at different positions, placed over the packing line, packed into trays, then transported to the laboratory in southeast Queensland, where they were ripened and assessed for damage.

6.1.2.2. Materials and methods - Trial 1

6.1.2.2.1. Harvesting and treatments

Fruit were harvested from Oolloo Farms (K1) in Katherine, NT on the 8th of November 2006, using standard commercial practice (harvest aids). Fruit were placed directly into 350 kg plastic field bins, lined (both bottom and sides) with plastic or 1½ corrugated cardboard, or not lined, as shown in Table 48. The bins were not washed before use. Fruit were transported from the farm to the Nighthawk depot in Katherine (about 30 km) within four hours of harvest, or to Acacia Hills Farm in Darwin (about 200 km) within about ten hours of harvest. Air suspension trucks were used in both cases.

Table 48. Transport details of Calypso™ mango harvested from Oolloo Farms in Katherine, NT on 8th Nov 2006 and assessed for damage at different locations.

Treatment	Bin lining	Assessment location	Distance (km)	Time from harvest to assessment (hr)
30-Ctrl	Nil	Nighthawk depot	30	4
30-Cardb	Cardboard	Nighthawk depot	30	4
30-Plast	Plastic	Nighthawk depot	30	4
200-Ctrl12	Nil	Acacia Hills Farm	200	12
200-Ctrl	Nil	Acacia Hills Farm	200	24
200-Cardb	Cardboard	Acacia Hills Farm	200	24
200-Plast	Plastic	Acacia Hills Farm	200	24

6.1.2.2.2. Assessment at harvest and after transport

The fruit from each of the bins were inspected for damage associated with transport on arrival at Nighthawk, and on two occasions at Acacia Hills (on arrival 12 hours after harvest, and a further 12 hours later).

The slightest form of transport damage was recorded on every fruit irrespective of whether this would translate into quality loss on ripe fruit. A scale of 0-4 was used to rate the severity of the

damage, where 0=no damage to 4=severe damage (Plate 11). However, no severity higher than 2 was recorded.

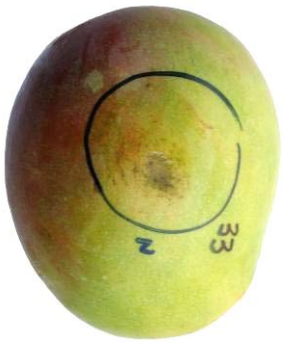
		
Severity rating 1	Severity rating 1	Severity rating 2

Plate 11. Severity ratings of skin damage in Calypso™ mango fruit following transport from the field to the packhouse in field bins.

The position of the fruit in the bin (top, middle, side, or bottom) was recorded, as well as the cause of damage: fruit to fruit, fruit to bin, or fruit to stem.

In addition, one extra bin with no lining was inspected for damage at the holding shed at Oolloo Farms, to assess the damage during harvesting and transport from the harvest aid to the shed. Every fruit in the bin was inspected and the severity of damage as well as the type of damage (cuts, bruises and impact damage) recorded.

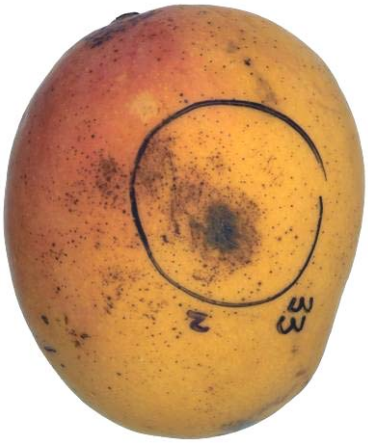
Following assessment, about four trays (48 fruit) were sampled at harvest from each bin at different positions and depths (top, middle, side, or bottom).

Fruit were put through the packing line under normal commercial practice, packed into trays and transported with a commercial mango load in a refrigerated truck direct to Brisbane. The fruit were collected from Brisbane and transported to the laboratory at Nambour by car.

6.1.2.2.3. Assessment at ripe

Fruit were ripened at 20°C with 10 ppm ethylene for 2 days, then held at 20°C until ripe (based on skin colour).

Firmness, lenticel spotting and skin browning, as well as abrasion damage from skin rubbing, and mechanical damage (mainly depressed or flattened areas on the skin caused by pressure damage) (Plate 12) were rated based on the area of the skin affected, using the 0-4 scale as shown in Table 47.



Abrasion damage

Mechanical damage

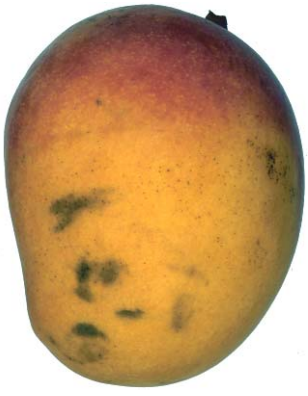
Plate 12. Types of skin damage in ripe Calypso™ mango fruit that had been transported from the field to the packhouse in field bins.

Table 49. Rating systems used for fruit firmness, lenticel spotting, skin browning, discrete browning, abrasion damage, and mechanical damage of Calypso™ mango.

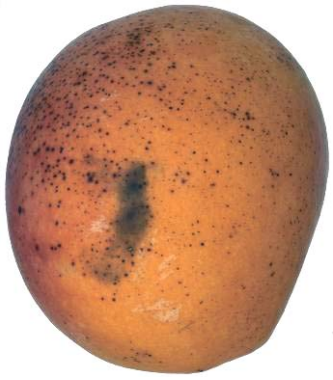
Rating	Hand firmness	Area of the skin affected				
		Lenticel spotting	Skin browning	Discrete browning	Abrasion damage	Mechanical damage
0	Hard	Nil	Nil	Nil	Nil	Nil
1	Rubbery	To 10%	To 3cm^2	To 0.25 cm^2	To 0.25 cm^2	To 0.25 cm^2
2	Sprung	To 25%	To 6 cm^2	To 1 cm^2	To 1 cm^2	To 1 cm^2
3	Soft	To 50%	To 25%	To 2 cm^2	To 2 cm^2	To 2 cm^2
4	Very soft	> 50%	> 25%	> 5 cm^2	> 5 cm^2	> 5 cm^2

A skin defect severity rating above two was assumed to cause a loss of saleability at wholesale/retail level.

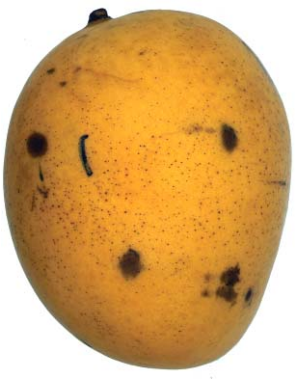
In addition, other skin marks characterised by localised but intense skin browning were referred to as discrete browning (see Plate 13) and rated as above. This form of damage did not seem to be directly associated with transport, but may be a result of stem contact with adjacent fruit. The contact points were not always depressed, and gave the impression of sap on the end of the stem still containing some spurt sap, and being forced in contact with the adjacent fruit.



At eating ripe



At eating ripe



8 days after eating ripe

Plate 13. Discrete browning in ripe Calypso™ mango fruit that had been transported from the field to the packhouse in field bins.

Fruit were left at 20°C for another 8 days, and rated again for the same defects.

6.1.2.3. Materials and methods - Trial 2

6.1.2.3.1. Harvesting and treatments

Fruit were harvested from Oolloo Farms (K1) in Katherine, NT on the 20th of November 2006, as in Trial 1. Fruit were placed directly into 450 kg plastic field bins, lined (bottom only) with 1½ corrugated cardboard, or thin cardboard (similar to that used for pallet liners), or no lining, as shown in Table 50. In one of the bins lined with 1½ corrugated cardboard, the fruit had the stem cut short at harvest using secaturs. Fruit were transported from the farm to the Yandilla packhouse in Katherine (about 30 km) or to Acacia Hills farm near Darwin (about 200 km) in air suspension trucks.

Table 50. Transport details of Calypso™ mango harvested from Oolloo farm in Katherine, NT in Nov 20 2006 and assessed for damage at different locations.

Treatment	Bin lining	Assessment location	Distance (km)	Time from harvest to assessment (hr)
30-Ctrl	Nil	Yandilla	30	4
30-1.5	Thick cardboard	Yandilla	30	4
200-Ctrl	Nil	Acacia Hills Farm	200	24
200-1.5*	Thick cardboard	Acacia Hills Farm	200	24
200-Thin	Thin cardboard	Acacia Hills Farm	200	24

* The fruit in this bin had the stem cut short at harvest.

6.1.2.3.2. Handling and assessment after transport

The fruit from each of the bins were rated for damage associated with transport on arrival at Yandilla (about 4 hours after harvest), and at Acacia Hills (about 24 hours after harvest). The slightest form of damage was recorded for every fruit irrespective of whether this would translate into quality loss on ripe fruit, using the same scales as in Trial 1.

The position of every damaged fruit in the bin (top, middle, or bottom) was recorded, as well as the type of damage (fruit to fruit, fruit to bin, or fruit to stem).

All transport-damaged fruit were carefully placed into trays for further assessment at ripe (see below).

In addition to the damaged fruit, about six trays (72 fruit) were randomly sampled from each bin at different depths (top, middle, or bottom, two trays per position), and fruit were individually identified according to position and type of damage.

As much as possible, the contact points of every sampled fruit in the bin (both between fruit and between fruit and bin) were circled with a permanent marker.

All sampled fruit (both the damaged fruit and those randomly sampled) were carefully put through the packing line, packed into trays, palletised, and transported to the laboratory at Nambour as described above.

6.1.2.3.3. Assessment at ripe

At the laboratory the fruit were ripened at 20°C and individually rated for firmness and defects as described in Trial 1.

Fruit were left at 20°C for another eight days, and rated again for the same defects.

In addition to the skin defects, the occurrence of flesh discoloration that caused some retail rejections of Calypso in Adelaide in 2006/7 was noted. Every fruit was cut and the severity of the damage was recorded using a 0-4 scale (where 0 = no damage and 4 = severe damage; Plate 14) based on the area of the flesh affected.

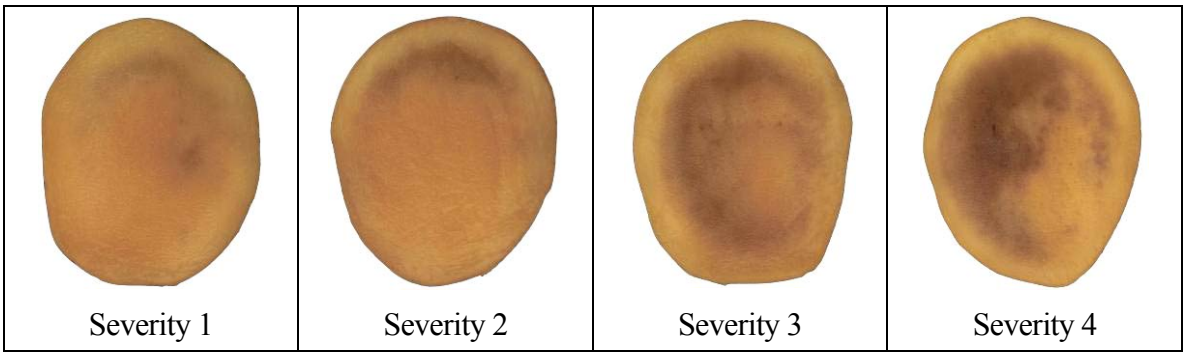


Plate 14. Severity ratings for flesh discoloration in ripe Calypso™ mango fruit

6.1.2.4. Results – Trial 1

6.1.2.4.1. Fruit at harvest and after transport

Based on the data in Table 51, the following observations can be made:

In general, the severity of damage observed directly after transport was very low, and would likely not have contributed significantly to the rejection during packing.

Generally, more damage was obvious when there was water or sap involved.

In relation to fruit to fruit contact, the damage appeared to be because of collapsing of the cells around the lenticels, giving a dark green halo around each lenticel.

There was little increase in damage in the control bins between 30 km transport (30-Ctrl), and 200 km (200-Ctrl) transport. There was also little difference between 12 hours and 24 hours in the bins.

In the control and the plastic lined treatments, most of the damage was because of fruit contact with the bin. Damage was greater if there was dust etc on the bottom, or if the bin bottom was damaged. In the cardboard treatments most damage was because of fruit to fruit contact and fruit to stem contact, mainly because fruit to bin damage was virtually eliminated in this treatment.

By far the biggest effect of bin lining was observed on bottom fruit. In these treatments, cardboard eliminated damage to the bottom fruit at the contact point with the bin. Any damage to fruit on the bottom or side of the bin was due to fruit to fruit or fruit to stem damage. Lining the side of the bin had less impact on fruit damage than lining the bottom of the bin.

There appeared to be an increase in damage to the fruit in the middle of the bin with cardboard and plastic lining. There was no logical explanation for this.

Plastic lining generally produced the greatest damage to "bottom" fruit mainly because water and wet sap was present for longer.

Most of the fruit-stem damage appeared to be caused by pressure of the stem against the fruit in combination with the sap oozing from the stem, rather than from pressure alone.

In relation to the percentage of the fruit in each location (internal, side, or bottom fruit) up to 60-80% of the bottom fruit were damaged when either no lining or plastic lining was used. Most of this damage was associated with pressure against the slats on the bottom of the bin. If some of the slats were broken, damage was greater.

Table 51. The percentage of Calypso™ mango fruit in each treatment bin in relation to fruit position in the bin and the type of damage caused between harvest and assessment. The fruit were assessed within 24 hours of harvest.

	Treatment						
	30-Ctrl	30-Cardb	30-Plast	200-Ctrl12	200-Ctrl	200-Cardb	200-Plast
% of fruit in relation to total fruit numbers in the bin							
Total not damaged	**87**	**96**	**79**	**89**	**85**	**84**	**72**
"internal" fruit	57	58	55	59	53	43	60
Fruit on sides of bin	15	20	16	14	14	20	8
Fruit on bottom of bin	15	18	8	17	18	20	4
Total damaged	**13**	**4**	**21**	**11**	**15**	**16**	**28**
Top of bin	2	1	2	1	0	2	3
Middle	2	2	5	2	5	8	10
Bottom	7	1	14	8	7	4	13
Side	2	0	1	1	3	2	1
Type of damage							
Fruit/fruit	2	2	5	1	1	8	9
Fruit/bin	8	0	13	7	9	0	13
Fruit/stem	4	2	3	3	5	9	6
Incidence: % of damaged fruit in relation to total per position							
Side	13	0	5	4	17	10	16
Bottom	32	5	64	32	26	18	78
Other	7	5	11	4	9	19	18

Note: excluded fruit taken for ripening (4 trays per bin).

6.1.2.4.2. Harvest damage

About 6% of the fruit had evidence of harvest damage (Table 52). 3.5% of this fruit had cuts (broken skin and worse), 1.4% had bruises (straight marks but no broken skin) and only 1% had evidence of impact damage that could be associated with fruit to fruit contact.

The average severity for all types of damage was 1.3, with little variation between the type of damage. However, all fruit with cuts would have been downgraded to reject status. Bruised fruit may not have been rejected during sorting, but may have resulted in marks showing up on the ripe fruit at retail level.

Harvest aid design and/or operation should be further investigated to minimise any form of mechanical damage to fruit during harvesting.

Table 52. The number and percentage of Calypso™ mango fruit with damage in the field bin, as well as the type of damage, as assessed at the packing shed immediately after harvest.

	Fruit number	Percentage of fruit affected
Total fruit number in bin	518	
No damage	488	**94**
Damaged[1]	30	**6**
Types of damage		
Cuts	18	**3.5**
Bruises	7	**1.4**
"Impact" damage.	5	**1.0**

[1] excluding field marks etc

6.1.2.4.3. At eating ripe

Most of the transport damage identified in the bins did not result in significant quality loss for the ripe fruit (Plate 15). Although 36% of the sampled fruit had some form of skin defect more directly associated with transport, only 0.6% of those fruit had a severity rating higher than 2 for any of the

rated defects (Table 53). There was little difference in the incidence of skin damage between fruit transported about 30 km compared with 200 km (Table 53).

Plate 15. Skin damage in Calypso™ mango fruit following transport from the field to the packhouse in field bins, and the same damage at the eating ripe stage.

Mechanical damage was less severe for the fruit transported in bins lined with cardboard (Table 54). A similar trend was observed for abrasion damage, but the treatment differences were not statistically significant.

Across all treatments, abrasion damage was on average more severe in ripe fruit than mechanical damage (Table 54, Plate 16).

Table 53. The incidence (%) of ripe Calypso™ mango fruit with any level of abrasion or mechanical damage (severity rating higher than 0), and of fruit with a severity rating higher than 2. Fruit were sampled four or 24 hours after harvest, following transport in field bins for about 30 or 200 km. Results are based on the number of fruit across the treatments 30-Ctrl, 30-Cardb, and 30-Plast (for the 30 km transport data), or across the treatments 200-Ctrl, 200-Cardb, and 200-Plast (for the 200 km transport data).

Sampled fruit at harvest	Fruit number	% of ripe fruit	
		With any level of damage*	With severity higher than 2
30 km transport	165	38	0.6
200 km transport	178	35	0.6
Total	272	36	0.6

= includes abrasion and mechanical damage.

Table 54. The severity (0-4 rating) of abrasion and mechanical damage in ripe Calypso™ mango fruit, following transport in field bins lined with cardboard, plastic, or no lining, for about 30 or 200 km. Numbers within the same columns with different letters are statistically different ($p < 0.05$). There was no significant treatment effect on abrasion damage.

Treatment	Severity ratings (0-4)	
	Abrasion	Mechanical damage
30 – Ctrl	0.39	0.14 [ab]
30 – Cardb	0.28	0.03 [b]
30 – Plast	0.38	0.22 [a]
200 – Ctrl 12	0.25	0.15 [ab]
200 – Ctrl	0.42	0.22 [a]
200 – Cardb	0.25	0.03 [b]
200 – Plast	0.44	0.08 [b]
Mean	0.34	0.11
LSD	ns	0.15

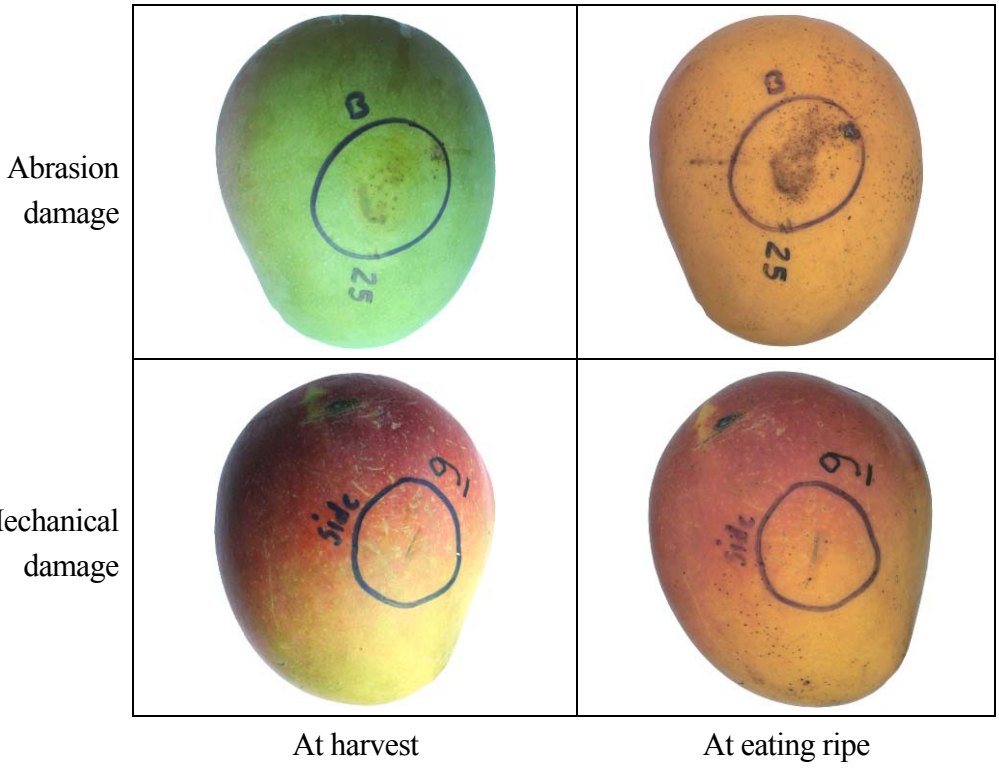


Plate 16. Abrasion and mechanical damage in green and ripe Calypso™ mango that had been transported from the field to the packhouse in field bins.

Lenticel spotting severity was generally higher in ripe fruit that had been transported 200 km (ratings from 0.6 to 1.0 depending on the treatment, data not shown) than to 30 km (ratings of 0.3 to 0.6). The causes of this uncertain, but may be related to sap remaining on the fruit for longer before packing.

There were no treatment differences in the severity of skin browning and discrete browning (both with and average of 0.4, data not shown).

Eight days after the eating ripe stage

There were no treatment differences in the severity of defects eight days after eating ripe, including abrasion and mechanical damage, discrete browning, skin browning, and lenticel spotting (data not shown).

There was little increase in the severity of abrasion (average rating across all treatments of 0.3) mechanical damage (average rating of 0.1) or discrete browning (from a rating of 0.4 to 0.5) between eating ripe and 8 days later (data not shown).

In contrast, lenticel spotting severity increased from 0.7 at eating ripe to 3.0 eight days later.

6.1.2.5. Results - Trial 2 (Mid-late harvest)

6.1.2.5.1. Fruit at harvest and after transport

Based on the data in Table 55, the following observations can be made:

Damage at harvest was considerably less in this trial compared with Trial 1, despite the fact that larger field bins were used in the present trial. This is possibly due to more mature fruit and hotter weather resulting in fruit with less water in them (the cells would be less turgid or more "spongy"), and therefore more resistant to impacts. If this was the case, there may be some benefit to holding fruit at the farm for one day after harvest before transporting to the packhouse, or reducing irrigation just before harvest.

There was more damage to fruit when transported 200 km compared to 30 km. This was consistent across all treatments. The increased damage with longer transport occurred mainly to the fruit in the middle of the bin, compared with fruit on the top or the bottom of the bin.

Lining the bottom of the bin with cardboard again reduced damage due to bin contact. There was no obvious difference between using thin cardboard (similar to that used as pallet liners) compared with thicker cardboard.

Stem damage was the main reason for the increase in damage with longer transport. This may have been a combination of the longer transport distances increasing damage, or the longer contact times between the stem and the fruit in the 200 km treatments. Longer transport had no consistent effect on fruit to fruit damage. Removing the stem button from the fruit at harvest using secateurs did not significantly reduce stem damage to fruit when transported up to 200 km.

6.1.2.5.2. At eating ripe

Visible transport damage was less just after transport, but skin quality loss on the ripe fruit was greater compared to Trial 1.

At ripe, about 4.4% of the fruit that had been randomly sampled through the bin had some sort of skin damage typically associated with transport (Table 56). However, only 0.2% of those fruit presented a severity rating higher than 2 for either abrasion, or mechanical damage (Table 56). Since this incidence is higher than in the incidence of transport damage just after transport (2.3%), it appears that some harvest or transport damage was not visible at the packhouse, but appeared as the fruit ripened.

Of the fruit that showed some transport damage at the packhouse just after transport ("Damaged" in Table 10), almost 50% showed some level of transport damage when ripe, but less than 2% of these fruit showed severe damage (greater than two). This confirms that most of the damage observed just after transport had little effect on appearance of the ripe fruit.

Only 3.4% of all contact points in the sampled fruit resulted in typical transport damage symptoms when ripe. This again confirms the minimal impact of up to 200 km transport on ripe fruit quality.

Table 55. The percentage of Calypso™ mango fruit in each treatment bin in relation to the fruit position in the bin and the type of damage caused between harvest and assessment.

	Treatment				
	30-Ctrl	30-1.5	200-Ctr	200-1.5*	200-Thin
% of fruit in relation to total fruit numbers in the bin					
Total not damaged	98.7	99.2	97.3	97.4	96.8
All but fruit on bottom of bin	85.3	88.0	86.5	82.8	84.2
Fruit on bottom of bin	13.3	11.2	10.9	14.6	12.6
Total % damaged	1.3	0.8	2.7	2.6	3.2
Top	0.1	0.2	0.2	0.5	0.5
Middle	0.0	0.5	1.6	1.5	2.4
Bottom	1.2	0.2	0.9	0.5	0.3
Type of damage					
Fruit/fruit	0.0	0.3	0.2	0.3	0.8
Fruit/bin	1.3	0.2	1.0	0.4	0.7
Fruit/stem	0.0	0.3	1.5	1.9	1.7
Incidence: % of damaged fruit in relation to total per position					
Top	7.7	20.0	6.9	20.8	15.2
Middle	0.0	60.0	58.6	58.3	75.8
Bottom	92.3	20.0	34.5	20.8	9.1

* The fruit in this bin had the stem cut short.
Note: excluded fruit taken for ripening (total of 72 fruit per bin).

Table 56. The incidence (%) of ripe Calypso™ mango fruit with any level (severity rating higher than 0) of abrasion and mechanical damage, and of fruit with a severity rating higher than 2. Fruit were sampled 4 or 24 hours after harvest following transport in field bins to about 30 or 200 km. Results were calculated based on the total number of fruit within the treatments 30-Ctrl and 30-1.5 (for the 30 km transport), and within the treatments 200-Ctrl, 200-1.5, and 200-Thin (for the 200 km transport).

Sampled fruit at the packhouse	Fruit number	% of fruit at eating ripe	
		With any level of damage*	With severity higher than 2
Randomly sampled through the bin	360	4.4	0.2
After 30 km transport	144	5.8	0.5
After 200 km transport	216	3.4	0.0
Damaged	105	49.5	1.9
After 30 km transport	16	56.3	0.0
After 200 km transport	89	48.3	2.2
Total (randomly + damaged)	465	14.6	0.6
After 30 km transport	160	10.9	0.5
After 200 km transport	305	16.5	0.6

* = includes abrasion, and mechanical damage.

Abrasion was more severe in fruit sampled from the bottom (severity rating of 0.22) of the bin compared with fruit from the top (0.05) or the middle (0.08) layer of the bin (averaged across all treatments; data not presented). Abrasion appears to be caused by rubbing the fruit, particularly against abrasive surfaces such as the bottom of the bin containing dust or fine gravel. This again confirms the benefits of a bottom liner, and maintaining clean bins.

There were little treatment differences in average severity for most defects, including sap lenticel, abrasion, and mechanical damage (data not shown).

Discrete browning

In addition to the above defects, about 53% of the fruit sampled randomly through the bin had discrete browning at ripe, which was not visible just after transport, but only appeared on fruit after several days of ripening. About 4.4% of those fruit had a severity rating higher than 2.

This type of discrete browning on the skin has been occasionally observed on Calypso™. The exact causes are unknown, but may be a form of localised but intense skin browning associated with contact with the stem in the field bin at the end of the harvest aid. By this stage most of the spurt sap would be gone, but low concentrations of sap on the stem end, then contact between the stem and the fruit could cause this localised browning.

Generally, discrete browning was not associated with any contact points of the fruit in the bin, and occurred in all positions around the fruit. From a general observation (no rating assessments were made), it appears that the areas of discrete browning darkened (from a light brown to a dark brown) as the fruit ripened, but the affected area did not increase over time. Also, there was no significant difference in discrete browning severity between fruit sampled at the top, middle or bottom layer of the bin.

We suspect that this damage occurs during or soon after harvest, and because of its intermittent occurrence may be affected by time of harvest in the day, tree water status and harvest aid operation such as time in the detergent etc. Further monitoring of this damage may be warranted.

6.1.2.5.3. Eight days after eating ripe

In contrast to Trial 1, there was little change in the severity of both abrasion (average rating of 0.3) and mechanical damage (average rating of 0.4) between ripe and eight days later for the fruit that had showed some transport damage just after transport .

Similarly, there was little variation in the severity of discrete browning between ripe and eight days later (average rating of 0.8).

In contrast, as observed in Trial 1, lenticel spotting increased from a rating of 1.5 at eating soft to a rating of 3.3 eight days later.

About 33% of the fruit had symptoms of flesh discolouration, with an average severity of 1.4. However, only 2% of these fruit had a severity rating higher than 2. The causes of this flesh discoloration are unknown, but may be related to poor postharvest handling, especially fruit not being placed in cold storage quickly, and fruit partially ripening at these lower temperatures. For example the fruit in this trial were harvested on Monday, placed in cold storage on Wednesday, and held for eight days after reaching eating soft.

6.1.2.6. Conclusions and recommendations

Just after transport

- Only 13% of fruit showed any damage immediately after transport to the packhouse, but the severity of damage was very low and would not have caused fruit to be rejected on the packing line. Most of this damage observed just after transport did not result in damage to the ripe fruit.
- There was more transport damage (especially due to stem damage) when fruit were transported 200 km compared to only 30 km. However, these differences did not translate to more severe damage of ripe fruit.
- Most of the damage was to fruit on the bottom of the bin. Dust and grit in the bin contributed to fruit damage. Lining the bottom of the bin with cardboard (even a thin one similar to that used as pallet liners) significantly reduced damage due to bin contact.
- Generally, more damage was obvious when there was water or sap involved.

- Removing the stem button from the fruit at harvest did not significantly reduce stem damage to fruit when transported up to 200 km.
- Damage at harvest was considerably less in the later trial (more mature fruit). This may be due to more mature fruit and hotter weather resulting in less turgid, more resistant fruit.

At ripe

- About 15-36% of fruit sampled at harvest had some sort of damage at ripe that we attributed to transport, suggesting that not all transport damage is obvious in the packhouse. However, only about 0.6% of these fruit had severity rating higher than 2 for any of the rated defects.

On the basis of the above:

- Generally, there was virtually no commercially significant damage to fruit transported up to 200 km from the field to the packhouse. Most damage would not have resulted in rejection during packing, and contributed little to quality loss when ripe. Practices to consider include:
    - Washing field bins after every use to remove dust and grit from the bottom of the bin.
    - Lining the base of the bin with thin cardboard to reduce damage.
    - Packing the fruit as soon as possible after arrival at the packhouse. Prolonged contact with water and sap will increase lenticel spotting.
    - The results suggested that the stem "button" remaining on the fruit after snap picking contributed little to transport damage. Most of the stem-fruit damage appeared to be the result of some sap remaining on the stem end, which was not affected by the presence or absence of the button.

Other comments include:

- Up to about 50% of fruit sampled at harvest had discrete browning at ripe, with less than 5% of those fruit had a severity rating higher than 2. Symptoms did not appear to be associated with any contact points of the fruit in the bin and were not visible at the time of harvest. The causes of this defect are uncertain, but may be related to a small amount of dilute sap remaining on the stem, and the stem contacting fruit during harvest causing a small area of intense skin browning.

  These symptoms were not commonly observed in other consignments we received for other trials, but the causes are still worth investigating since it was a significant factor in downgrading of ripe fruit in the second trial. It is unlikely to be due to transport damage, but more likely a result of harvesting systems, and perhaps time from harvest to removal of sap during packing.
- About 5% of the fruit were damaged during harvest, mostly from cuts. Greater attention is required to minimise mechanical damage during harvesting. This could be achieved by improving both the design and operation of harvesting systems.
- About 33% of the fruit had symptoms of flesh discolouration similar to that observed in rejected commercial consignments in Adelaide in December. However, only 2% of these fruit had a severity rating higher than 2. The causes of this discoloration are unknown, but may be related to fruit not being placed in cold storage quickly, and fruit partially ripening at these lower temperatures.

6.1.3. Fruit sensitivity to impacts

6.1.3.1. Introduction

During the retail surveys of the previous Calypso™ mango project, skin marks were often observed on fruit on the shelf. The nature of these marks suggested that the fruit had been exposed to impacts during harvesting and packing, with the damage only becoming obvious as the fruit ripened and became over-ripe (in some instances). It seems unlikely that damage occurs while the fruit ate in the tray. Given the move to one-touch systems in the retail store, it is also unlikely (although possible) that the damage would occur at that point. Therefore, we consider the most likely stages for this damage would be during harvesting, and before packing.

This type of damage is often not visible during grading but can detract considerably from saleability at retail level. One of the objectives within the current project (in conjunction with the Deliverance project) is to evaluate current harvesting and packhouse systems/operations in relation to their impacts on quality. An understanding of the susceptibility of Calypso™ mango to impacts is important to critically evaluate current practices, and develop improved ones.

Previous studies on the susceptibility of 'Kensington Pride' mango to impact damage (Ledger 1991) concentrated on flesh damage, with no assessment of skin damage. This trial used similar methods to the Ledger study, but looked at both skin and flesh damage.

Fruit were harvested at about 6 a.m. in the morning. At this time, the fruit were most likely to be fully turgid (that is, the cells as full as possible with water) and most sensitive to impact damage. The fruit were impact-treated immediately after harvest, and again one and two days after harvest. The fruit would have lost some water over this period, and susceptibility to impacts was expected to be less.

6.1.3.2. Methods

6.1.3.2.1. Fruit

Calypso™ mango fruit were harvested at commercial maturity on 14th Feb 2007 from Oolloo Farms, Bundaberg. 270 blemish-free fruit were harvested and carefully placed into trays in the field. Immediately after harvest 12 fruits were subjected to drop heights of either 10, 25, 50, 75, 100 or 150 cm against a brick wall at the packhouse.

All fruit were then transported to the laboratory and held under shade to simulate situations where fruit are picked and packed the next day under commercial conditions. One and two days after harvest a further 12 fruit per drop height were treated in the same way as at harvest (zero days). The fruit were then held at 20°C until ripe.

6.1.3.2.2. Impact treatment

Individual fruit were placed in a plastic bag with the side cut out to expose the side of the fruit. The bag was firmly suspended by two strings attached to nails in the brick wall of the packhouse. The height from the ground to the middle of the fruit was measured with the fruit sitting freely against the wall. The drop height onto the brick wall was measured as a difference between the height at the top of the arch, and the height at the bottom of the arch when the fruit hit the wall (Plate 17).

A smooth section of brick was chosen for the point of impact with the fruit, so that the fruit hit a smooth surface. The point of impact on the fruit was immediately marked with a marker pen.

6.1.3.2.3. Assessments

The fruit were rated for skin damage immediately after harvest, five days after treatment (5-7 days after harvest), and at ripe (12 days after harvest). A rating scale of 0-4 was used, with 0= no damage, and 4 = severe damage (see Plate 19).

At ripe (at the final skin damage assessment 12 days after harvest), the fruit were cut through the point of impact, and the severity of damage to the flesh was recorded as the percentage of flesh volume affected. When required, several sections were made through the fruit to accurately estimate the volume affected.

Plate 17 Method used for applying impacts to Calypso^{TM} mango fruit.

6.1.3.2.4. Statistical analysis

Each fruit was considered as a replication, providing 12 single fruit replications per treatment.

The skin damage results were analysed as a three-way factorial: drop height x days between harvest and treatment x assessment time. The interaction between the three factors was not significant, so only interactions between impact height and days between harvest and treatment (averaged across assessment time after harvest), and impact height and assessment time (averaged across days between harvest and treatment) are presented. For flesh damage, the interaction between drop height and days between harvest and treatment was significant.

6.1.3.3. Results

There was very little skin damage from impacts, even in the most severe treatments (Figure 43). Across all treatments, only 9% of the fruit showed skin damage, and even when fruit was dropped at a height of 150 cm, only 16% of fruit were damaged. Where skin damage occurred, in most cases it was minor, and not commercially significant (rating of 2 or less).

When fruit were dropped immediately after harvest, there was no significant skin damage with drop heights up to 100 cm, but 150 cm produced some skin damage (Figure 43a). Holding the fruit for one day before impact significantly reduced damage, so that there was no damage at any height. Holding for two days resulted in statistically significant damage with

50 and 75 cm drops but no damage with 100 and 150 cm. The reasons for this pattern is unclear. The 150 cm treatments demonstrated that holding fruit for several days after harvest by reduce impact damage to the skin, presumably because of slight dehydration and "softening" of the skin cells.

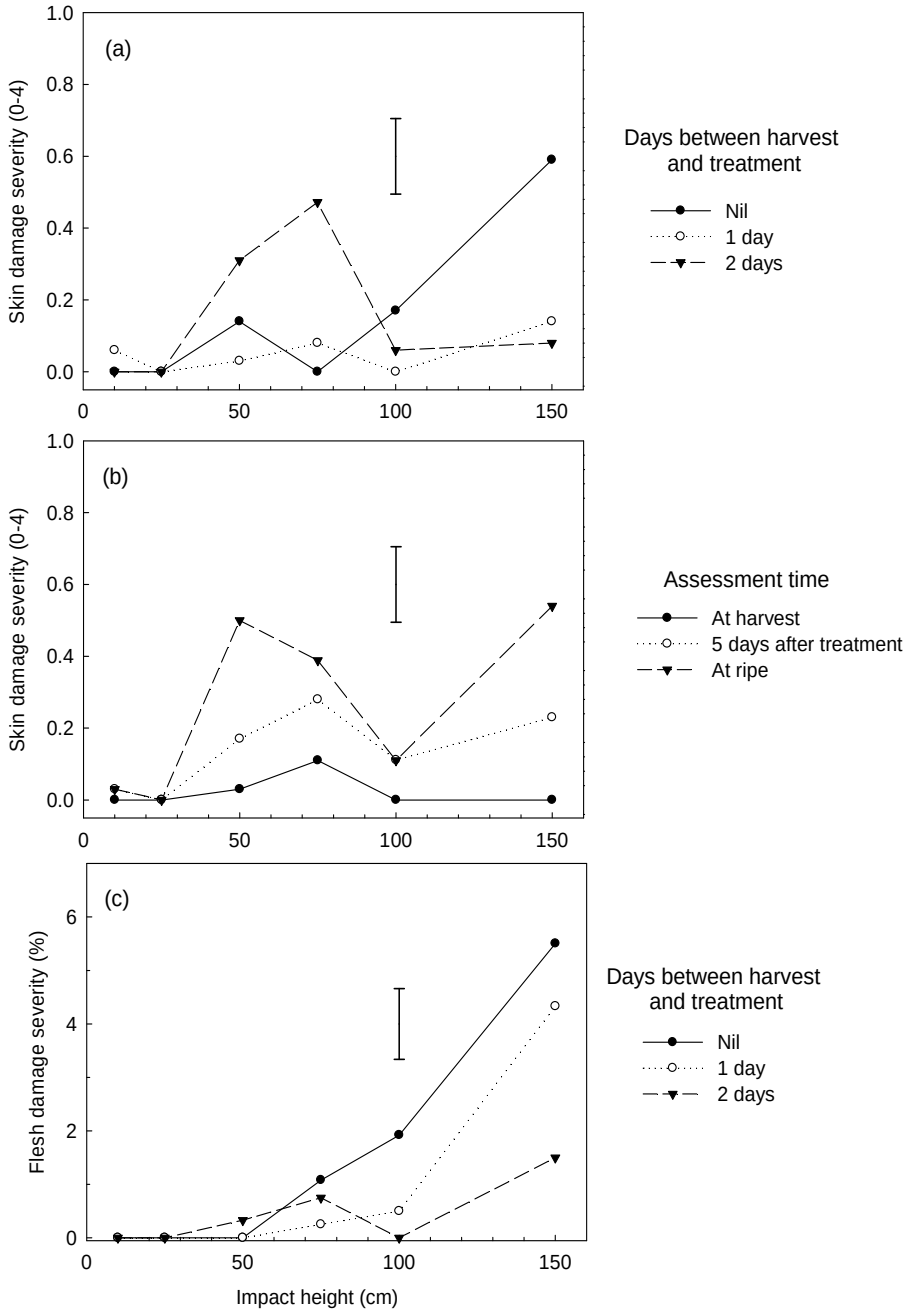


Figure 43. Calypso^{TM} mango fruit 'dropped' from 10-150 cm onto a brick wall, either at harvest or one or two days after harvest (a), and assessed for skin damage (severity rating of 0=no damage to 4=severe damage) either at harvest, or five days after treatment, and at ripe (b). At ripe the damage to the flesh was also assessed as the percentage of flesh volume affected (c). For skin damage, the results are averaged across the three assessment times for this graph, and across the 'days between harvest and treatment' for the second graph. The bar on each graph indicates the least significant difference ($P<0.05$). Treatment differences greater than the length of the bar indicate statistically significant treatment effects.

With all drop heights, there was little evidence of skin damage immediately after treatment (Figure 43b). Skin damage became more obvious as the fruit ripened, and was generally most severe after 12 days.

The biggest effect of treatment was on flesh damage (Figure 43c; Plate 18 and Plate 19). Across all treatments, 20% of the fruit had some level of flesh damage. Flesh damage increased with drop heights of 100 cm and higher. 61% of the fruit from the 150 cm treatment had some flesh damage at ripe. However, with 150 cm drops, damage was significantly less when fruit were held for one and two days before treatment, compared with treatment just after harvest.

Plate 18 Flesh damage from impact against a brick wall. Symptoms varied from very small cracking, to larger cracks, white areas (possibly because of prevention of starch being converted to sugars during ripening), and finally to large cavities in the flesh.

Plate 19. Some symptoms of skin damage. On rare occasions skin "pitting" was observed (left), but usually only when the fruit hit a rough part of the brick. This damage was rated at severity of 4. With the higher drop heights (right), indentations occurred because of flesh damage underneath, but even in these instances skin damage was rare.

6.1.3.4. Conclusions and recommendations

Damage to the skin

- There was little commercially significant damage to the skin, even with the largest drop heights. Damage was most severe when fruit hit rough sections of the brick wall.
- There was effectively no skin damage with drop heights between 10-100 cm (except at 75 cm in one treatment). Damage increased significantly with 150 cm drop height, but only for fruit treated immediately after harvest. A delay of 1-2 days between harvest and treatment resulted in effectively no damage. This would suggest that packing fruit one day after harvest reduces the risk of mechanical damage during handling.
- There was generally no skin damage immediately after treatment. Damage only became obvious at five days. Therefore, damaged fruit could not be removed during sorting, but damage would be visible as fruit ripen on the retail shelf.

Damage to the flesh

- Impacts caused more damage to the flesh than to the skin, but again these were significant only if the impacts occurred immediately after harvest, and at heights greater than 75 cm.
- As with skin damage, a two day delay between harvest and treatment reduced flesh damage at drop heights of 100-150 cm, compared with no delay. This again confirms the benefits of delaying packing to reduce the risk of mechanical damage.

In summary, the skin of Calypso^{TM} mango was surprisingly resistant to impacts against a smooth surface, but we suspect that damage would increase significantly with impacts against rougher surfaces. Drops of 75 cm height or more should be avoided to reduce skin and flesh damage. Delaying transporting/packing for 1-2 days after harvest may reduce the risk of damage from impacts.

Therefore, it is unlikely that fruit-to-fruit contact during normal commercial operations will cause skin damage. However, fruit-to-stem impacts, and contact with sharp edges of the

harvest aid and packing line are more likely to cause the skin marking observed on fruit at retail level. This will be investigated in more detail next season.

6.1.4. Disease control

6.1.4.1. Acidified procloraz

6.1.4.1.1. Introduction

Prochloraz (Sportak®) is currently the main fungicide treatment after harvest for the control of rots in Calypso™ mango. Research in other mango cultivars has shown that acidifying the Prochloraz solution may allow lower concentrations to provide effective control against *Alternaria*.

The potential benefits of applying an acidified Sportak in controlling postharvest rots on Calypso™ mango was investigated.

6.1.4.1.2. Procedures

Calypso™ fruit were harvested on the 8th of February 2008 from Simpson Farms (Childers) and Oolloo Farms (Bundaberg), and transported to Brisbane. Fruit was dipped in treatment solutions on the 9th of February. Two replicate trays of 16-18 fruit per farm were used (total of 68 fruit per treatment).

Prochloraz as the commercial formulation Sportak® (a.i. 450 g/L Prochloraz), and hydrochloric acid (30%, approximately 8.7M) were used as a 30 second dip at room temperature at the combinations and concentrations given in Table 57. After treatment the fruit were dried, repacked, and ripened at 22-23°C, 65%RH, with no ethylene treatment.

Table 57 Fungicide treatments applied to Calypso™ mango after harvest.

Treatment	Combination	Volume in 40 L of water
Control	Nil	Nil
HCl	Hydrochloric acid (30%)	218 mL HCl
Sportak	Sportak standard concentration (0.55 mL/L)	22 mL Sportak
Sportak low	Sportak low concentration (0.11 mL/L)	4.4 mL Sportak
Sportak+HCl	Sportak (0.55 mL/L) + HCl (30%)	218 mL HCl + 22 mL Sportak
Sportak low+HCl	Sportak (0.11 mL/L) + HCl (30%)	218 mL HCL + 4.4 mL Sportak

The days to ripe were determined based on fruit firmness, assessed by gentle hand pressure. The background skin colour was rated using the following scale: 1=0-10% yellow, 2=10-30% yellow, 3=30-50% yellow, 4=50-70% yellow, 5=70-90% yellow, and 6=90-100% yellow. The rating refers to the percentage of the background skin colour area showing yellow and not the percentage of the whole skin area. Skin damage was rated based using the following scale: 0=nil, 1=light, 2=moderate, 3=severe.

The severity of rots were assessed on every fruit based on the percentage of the area of the skin affected. Rots were rated separately depending on their position on the fruit (side or stem) and the pathogen (*Colletotrichum* or *Dothiorella*/*Lasiodiplodia*; referred to as *Dothiorella* in the rest of the report). Isolations were taken and the pathogens identified.

Within each treatment, the incidence was calculated as the percentage of fruit with each type of rot. The percentage of saleable fruit was calculated as those with a severity rating of 10% or less for all rots combined.

6.1.4.1.3. Results

Fruit quality results are presented in Table 58.

The severity of total stem, total *Colletotrichum* and total *Dothiorella*, and incidence of total stem lesions was significantly reduced by Sportak (low or standard concentration) with or without HCl, compared with control or HCl only. The severity of total *Colletotrichum* was also reduced by HCl

alone, compared with control. Total *Dothiorella* incidence was also reduced by most Sportak treatments.

Table 58 Severity and incidence of side and stem rots, and percentage of saleable fruit on ripe Calypso™ mango dipped in different chemical solutions after harvest. "Stem total" = sum of *Colletotrichum* and *Dothiorella* lesions occurring around the stem. "*Colletotrichum* total" = sum of *Colletotrichum* lesions occurring at the stem and on the body of the fruit. "*Dothiorella* total" = sum of *Dothiorella* lesions occurring around the stem and on the body of the fruit.. Means within columns with different letters are significantly different ($P \leq 0.05$) as tested by least significant difference (LSD).

Treatment	Severity (%)			Incidence (%)			Saleable
	Stem total	*Colletotrichum* total	*Dothiorella* total	Stem total	*Colletotrichum* total	*Dothiorella* total	fruit* (%)
Control	4.2 [a]	1.6 [a]	3.2 [a]	13.4 [a]	12.2	8.3 [ab]	90
HCl	2.9 [a]	0.2 [b]	3.0 [a]	8.3 [a]	4.2	11.1 [a]	93
Sportak	0.3 [b]	0.0 [b]	0.3 [b]	2.8 [b]	1.4	2.8 [bc]	99
Sportak low	0.5 [b]	0.2 [b]	0.3 [b]	4.2 [b]	2.8	1.4 [c]	99
Sportak + HCl	0.4 [b]	0.2 [b]	0.3 [b]	2.8 [b]	4.2	1.4 [c]	97
Sportak low + HCl	0.4 [b]	0.5 [b]	0.3 [b]	2.8 [b]	6.9	1.4 [c]	97

Results are the means of 16-18 fruit per tray/rep (total of 68 fruit per treatment).

Severity = percentage of skin or flesh area affected by rots.

Incidence = percentage of fruit affected by rots in relation to the total number of fruit within each treatment.

*Saleable fruit (%) = percent of fruit with a severity rating below 10% for all rots combined.

There were no treatment effects on severity or incidence of side rots caused by *Colletotrichum* (average of 0.2% for severity and 4.1% for incidence) or by *Dothiorella* (average was virtually nil for severity and 0.5% for incidence).

There were no treatment effect on days to ripe (average of 15.2) or skin colour (average of 5.8). There was no skin damage or denditric spot in any of the treatments.

Sportak is not known for its efficacy against *Dothiorella*/*Lasiodiplodia*, though we have occasionally observed similar results to these in the past. It was also interesting that HCl alone had some effect against *Colletotrichum*.

The *Colletotrichum* levels in this trial were very low, so further studies next season would be warranted.

6.1.4.1.4. Conclusions

- The severity and incidence of SER lesions (excluding stem-end anthracnose) was significantly reduced by Sportak (low or standard concentration) with or without HCl.
- The severity of side + stem-end lesions caused by the SER fungi (ie. total 'Dothiorella') was significantly reduced by Sportak (low or standard concentration) with or without HCl.
- The incidence and severity of total stem-end lesions (ie. anthracnose + *'Dothiorella'*) was significantly reduced by Sportak (low or standard concentration) with or without HCl.
- The severity of side + stem-end lesions caused by *Colletotrichum* (ie. total anthracnose) was significantly reduced by all treatments including HCl alone.

6.1.4.2. Hot sprays

6.1.4.2.1. Introduction

A 52°C/five minute hot SpinFlo® fungicide treatment (dilution of 1mL/L) is recommended to control stem end rot and anthracnose on mango. This treatment was developed for hot water bath systems, which to date is the main application system used.

Hot water baths have several commercial disadvantages, including the need to heat a large volume of water, damage from the "paddles" required to ensure the accurate 5 min exposure in a flow-through system, and difficulty in preventing "hot spots" within the hot dip.

Spray tunnels can overcome a number of these disadvantages, and provide greater flexibility in treatment conditions if well-designed. A number of spray systems are in commercial use but to our knowledge their operating conditions and efficacy have not been well tested. This report characterises the performance of one hot fungicide spray system used to pack Calypso™ mangoes during the 2008/9 season. In the absence of specific recommendations for hot sprays, we have logically assumed that the units should achieve the same fruit temperature/time treatment as achieved using hot dips.

Other hot spray units have been tested within the Mango Deliverance project.

6.1.4.2.2. Materials and methods

Calypso™ fruit from Oolloo Farms Dimbulah were picked under normal commercial conditions and transported to the packhouse in bulk field bins. The fruit were the first harvest from young trees and were picked during an unusually wet period on 8th-9th December 2008.

At the packhouse, two trays of fruit (20-22 fruit per tray) were treated or sampled as follows:

- Control: No fungicide or spray/hot dip treatment. Fruit sampled just before going into the hot spray tunnel.
- Hot dip: Fruit sampled just before the hot spray tunnel and treated in a small hot dip at 52°C for 5 min using the recommended SpinFlo concentration.
- Hot spray: Hot spray treatment as per commercial procedures used in the packhouse

This was repeated two more times during the day at about 11:30am, 1:30pm and 4:50pm.

The hot spray unit consisted of a 1600 L reservoir with electronic temperature control, in tank agitation and a separate recirculation pump to ensure good fungicide suspension and temperature control, a three gas burner heating system, and an 8 m spray tunnel consisting of about 160 spray nozzles held about 30 cm above the fruit (Plate 20-Plate 22).

Plate 20 The hot water spray unit, with the hot fungicide spray reservoir underneath the spray tunnel.

Plate 21 The pump circulating the hot fungicide from the reservoir to the spray tunnel.

Plate 22 The gas-fired heating system for the hot spray unit.

To monitor tunnel temperatures, several hypodermic thermocouples were “floated” over the top of the fruit about 2 m into the spray race to estimate water temperatures near the fruit surface (Plate 23). Fruit surface temperatures immediately on exit from the spray tunnel were estimated with an infrared (IR) thermometer. The IR thermometer readings were compared to thermocouples placed about 2 mm under the skin of a sample fruit taken just after hot spray treatment.

Plate 23 Thermocouple wires holding the "hypodermic" thermocouples about 2 m inside the entrance to the spray tunnel.

A small (about 100 L) hot water bath was used to simulate commercial hot fungicide treatment. The bath consisted of a fibreglass tank with a recirculating pump to provide even temperatures

within the bath, and an electric heating element within the bath. Water and fruit surface temperatures were monitored using IR and under skin thermocouple probes and the temperatures recorded every 15-30 sec.

The fruit samples were airfreighted to the postharvest laboratories at Maroochy Research Station, Nambour, treated with 10 ppm ethylene for two days at 20ºC, then ripened. At 15 days after harvest fruit were rated for defects as shown in Table 59.

6.1.4.2.3. Results

The infrared (IR) thermometer provided an accurate estimate of fruit temperature just under the skin as indicated by hypodermic thermocouples (Table 60).

Table 59 Rating scales used for quality assessment.

Rating	Rots	Skin browning	Lenticel damage
0	Nil	Nil	Nil
1	< $3cm^2$	< $12cm^2$	< 10%
2	$3cm^2$ to $12cm^2$	12 cm^2 to 25%	10% to 25%
3	$12cm^2$ to 25%	25% to 50%	25% to 50%
4	> 25%	> 50%	> 50%

$3cm^2$ is the size of a 5 cent piece

$12cm^2$ is the size of a 20 cent piece

Table 60 Calibration of the infrared thermometer to estimate mango skin temperature just after hot spray. The thermocouple was inserted 1-2 mm under the skin. SD = standard deviation.

Test	No of readings	"Skin" temperature (°C)			
		Thermocouple		Infrared thermometer	
		Average	SD	Average	SD
1	10	39.9	1.2	40.3	2.4
2	3	42	0.2	42.5	0.3

The fruit were in the spray tunnel for an average of 5 min 45 sec.

The temperature readout from the hot fungicide reservoir temperature controller was consistently about 2°C below the temperature recorded by the thermocouple (See graphs in Figure 44 for runs done at 1:30 and 4:50 pm). This may reflect an inaccurate temperature controller/probe, or a temperature gradient within the reservoir.

When the spray was turned on, reservoir temperatures dropped by about 2°C but increased to the set temperature after about 30 minutes (Figure 44). In the first test, the hot sprays were switched on for the first time that day. Near fruit surface temperatures (as measured by the thermocouples "floating" either the top of the fruit inside the tunnel) range from 42-48°C, which was about 3-9ºC below the measured reservoir temperature.

With the next two runs, the spray was switched on about 30-60 minutes before the start of temperature measurement and fruit sampling, but controller-measured reservoir temperatures were still below the 52°C setpoint (Figure 44). In the final run, the difference between actual reservoir temperature and the fruit surface temperature was less than earlier in the day, but still about 4°C below the actual water reservoir temperature.

Fruit surface temperatures immediately after emergence from the hot spray tunnel (measured by the IR thermometer) confirmed a temperature difference between the reservoir and fruit surface (

Table 61). These temperature readings were higher than those observed with thermocouples 1-2 m in from the spray tunnel entrance.

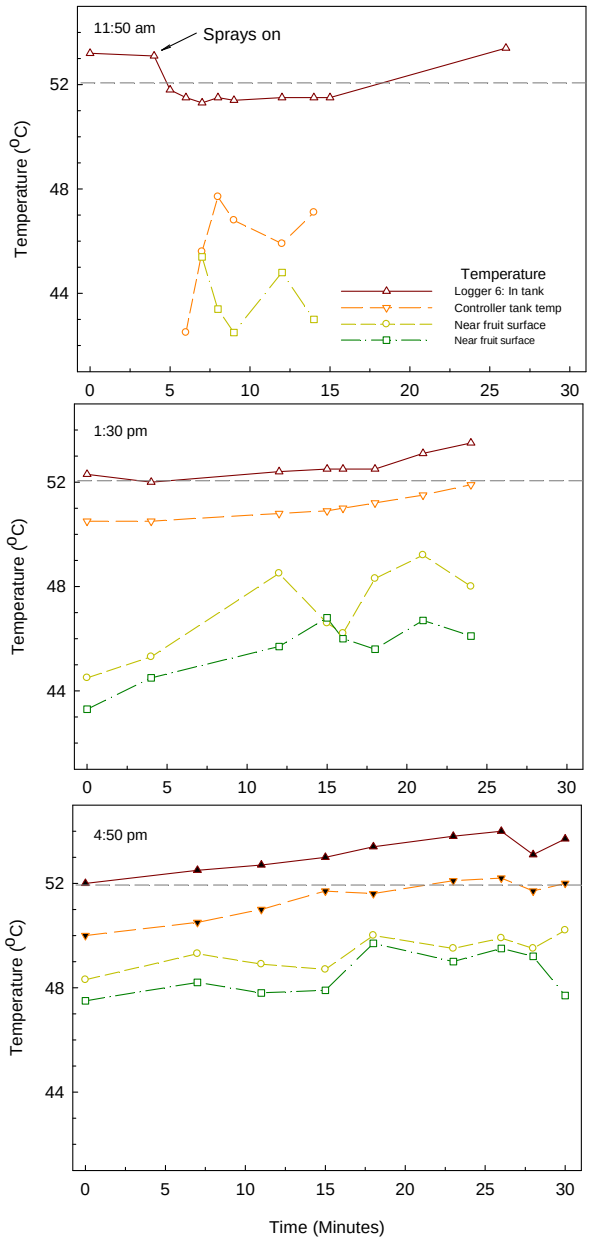


Figure 44 Temperatures during hot spray fungicide treatment of Calypso™ mango at three times during the day. One probe was placed in the hot spray reservoir tank and the other two probes "floated" over the top of the fruit about 2 m inside the entrance to the tunnel. The reservoir tank temperature controller readings were also monitored on the last two occasions.

Fruit temperatures during the hot dipping treatment increased rapidly within the first minute (Figure 45). Infrared-measured surface temperatures were about 50° within 1.5 minutes, while temperatures just under the skin (measured by thermocouple) increased more slowly after about one minute to reach about 48°C after five minutes.

Table 61 Surface temperatures (measured by the infrared thermometer) of Calypso™ mango fruit immediately on emergence from the hot spray tunnel. The readings were taken at two different times during the day. SD = standard deviation.

Test	No of readings	Surface temperature (°C)	
		Average	SD
1 (11.50 am)	20	47	1
2 (1.30 pm)	16	50.3	0.6

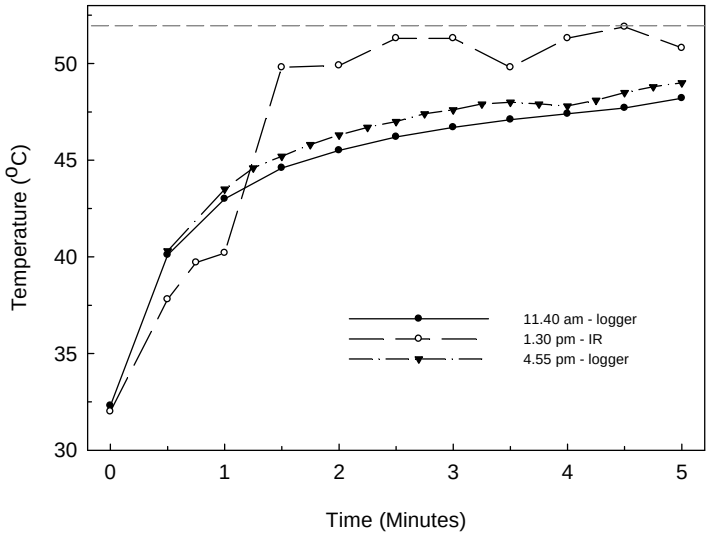


Figure 45 Temperatures during hot fungicide dipping of Calypso™ mango, repeated three times. Temperatures were measured with an infrared thermometer (IR) or using thermocouple probes inserted 1-2 mm under the skin.

The Infrared measured surface temperature after hot dipping for five minutes was close to the hot water set temperature of 52°C, while the similar measured temperature after 5 min 45 sec of hot spray was 47-50°C. This suggests that the hot spray system was not providing the same heat treatment to the fruit as hot dipping.
Design or operational modifications are required to ensure similar treatment conditions as with hot tips. These could include:

- Checking the accuracy of the controller temperature probe, or the location of the probe in relation to any temperature gradients within the reservoir.
- Holding the reservoir at about 56°C to ensure near fruit surface water temperatures of about 52°C.
- Decreasing the distance between the spray nozzles and the fruit
- Improving tunnel insulation
- Increasing water flow through the sprays or increasing the number of sprays. This assumes there is insufficient spray volume to prevent temperature drop between the spray nozzle and the fruit surface.

There was very little treatment effect on fruit diseases, maybe partly because of very low severity (Table 62). Lenticel spotting increased slightly, most likely because of water contact rather than a temperature affect. There was slightly more etch (a form of skin browning) on dipped versus sprayed fruit, possibly because of the higher temperatures experienced during dipping.

Table 62 Effect of hot fungicide treatment systems on quality of ripe Calypso™ mango. Fruit were either dipped at 52ºC for 5 min, or placed through the commercial hot spray unit (set temperature of 52ºC, and exposed for average of 5 min 45 sec). Numbers followed by the same letter within the same column are not significantly different at a 95% probability.

Treatment	Severity (0-4)				Saleable life index (%)
	Lenticel spotting	Skin Browning	Etch	Body rots	
Control	2.7 [c]	1.0	0.0 [c]	0.1	19
Dip	3.1 [b]	1.1	0.8 [a]	0.0	13
Spray	3.4 [a]	1.0	0.4 [b]	0.0	13
LSD	*0.3*	*ns*	*0.2*	*ns*	*ns*

- The fruit were exposed to the hot spray for an average of 5 min 45 sec.
- The estimated air/water temperature near the surface of the fruit about 2 m inside the entrance of the spray tunnel was 3-9°C below the reservoir water temperature. The difference between air/water and reservoir temperature was less with later runs compared to the first run of the day.
- The fruit surface temperature, estimated with an infrared thermometer indicated fruit surface temperatures at emergence from the spray was about 2-5°C below reservoir temperature.
- Infrared thermometer-estimated surface temperatures after 3-5 min of hot dipping was very similar to the hot water temperature of 52°C.
- These results suggest that the hot spray system with the reservoir temperature set at 52°C did not deliver the same heat treatment to the fruit as a hot dip system set at 52°C.

The following recommendations are based on the assumption that a hot spray system should try to mimic the temperature and duration recommendations developed for hot dip systems, until specific hot spray recommendations are available. These recommendations should also be discussed with a qualified engineer or similar.

- The accuracy of the reservoir temperature controller, and the existence of "hot spots" in the reservoir, should be checked.
- Increase the speed of the conveyor slightly to achieve a five-minute exposure to the hot spray.
- Once the controller and conveyer speed has been re-calibrated, the reservoir temperature should be set at about 56°C as a trial to achieve a fruit surface temperature of 52ºC, the air/water temperature checked at least four times during the day, and fruit samples taken to monitor quality.
- Other options for achieving the 52ºC fruit temperature could include increasing the number of nozzles or spray volume per nozzle, improving insulation around the spray tunnel, and reducing the distance between the nozzles and the fruit.
- Consideration could be given to modify the temperature control system to include a temperature probe in the spray tunnel near the top of the fruit, and the reservoir temperature adjusted to maintain near fruit tunnel temperature at 52°C.

6.1.5. Surface (wax) coatings

6.1.5.1. Introduction

Calypso™ mango is sensitive to lenticel spotting (LS), a superficial skin defect that affects fruit visual appearance after harvest, and is a significant quality issue for this cultivar. It can also be sensitive to dehydration and skin shrivelling, especially during prolonged storage or transport. Waxing is reported to reduce the incidence of lenticel damage in other cultivars.

The potential of four different coatings in reducing LS and skin aging in Calypso™ mango was investigated in a small preliminary trial this season, together with its effects on other fruit characteristics, including weight loss, firmness, skin colour, other skin defects, rots, Brix and flesh acidity.

6.1.5.2. Materials and methods

The treatments and coatings applied are given inTable 63.

Table 63 Form, supplier, and dilution of coatings treatments applied to Calypso™ mango after harvest.

Coating type	Commercial form	Supplier	Dilution
No coating	Nil	Nil	Nil
Carnauba wax	Natural Shine TFC210	Colin Campbell Chemicals Pty Ltd	3:1 (wax:water)
Polyethylene wax	Citrus Clear	Castle Chemicals Pty Ltd	Nil
Beeswax	Stone Fruit Wax	Castle Chemicals Pty Ltd	1:4 (wax:water)
Bio cover*	Natralife™	Natratec International Ltd	Nil

* = mixture of organic sources including olive oil and beeswax

Seventeen single fruit replicates per treatment were used (total of 85 fruit). Fruit were sampled from Oolloo Farms commercial packhouse in Bundaberg (QLD) on 8/2/08, sent to the laboratory (Maroochy Research Station – Nambour), and randomly assigned to each treatment within 20 hours of harvest. Fruit were individually weighed and coated with 0.5 ml of each coating solution using a syringe and rubber gloves to ensure uniform and complete coverage of the fruit surface. In the case of the Bio cover treatment, a sponge was used to allow rubbing between the coating and the fruit skin as recommended by the supplier.

Fruit were ripened at 20°C and the days to ripe determined based on fruit firmness (assessed by gentle hand pressure using the scale in Table 2). Firmness was also assessed using the Aweta Acoustic Firmness Tester, which measures the change in frequency as sound waves are transmitted through the fruit. The technique is rapid and non-destructive. Two readings were taken from opposite sides of the fruit around the middle section, and the results averaged per fruit. The tester also measures fruit weight, which was used to determine percentage weight loss.

The background skin colour was rated using the following scale: 1=0-10% yellow, 2=10-30% yellow, 3=30-50% yellow, 4=50-70% yellow, 5=70-90% yellow, and 6=90-100% yellow. The rating refers to the percentage of the background skin colour area showing yellow and not the percentage of the whole skin area.

The severity of lenticel spotting, skin browning, physical damage on the skin, rots, internal disorders, and off-odours were assessed on every fruit using the rating systems in Table 64.

For Brix and acidity of the ripe flesh, subsamples of flesh were taken from 5-6 fruit per treatment, and pooled to provide three samples per treatment. Brix (^{o}) was assessed using an Atago refractometer with temperature correction. Acidity (expressed as % of citric acid) was determined by mixing each combined sample with an electric hand held blender. Five grams

of the blended sample were diluted with 75 ml of distilled water before analysis using a Metrohm Titration system.

Table 64 Rating systems for fruit firmness, and severity of lenticel spotting, skin browning, physical damage, rots, internal disorders, and off-odours of ripe Calypso™ mango.

Rating	Hand firmness	Area of the skin or flesh affected		Off-odour
		Lenticel spotting	Skin browning, physical damage, rots, and internal disorders	
0	Hard	Nil	Nil	Nil
1	Rubbery	To 10%	To 3cm^2	Slight
2	Sprung	To 25%	To 6 cm^2	Moderate
3	Soft	To 50%	To 25%	Strong
4	Very soft	> 50%	> 25%	

3cm^2 is the size of a 5 cent piece

12cm^2 is the size of a 20 cent piece

Within each treatment, the percentage of saleable fruit was calculated as those with a severity rating below 3 for lenticel spotting or skin browning, or 1 or below for rots, or when the sum of defect ratings was 4 or below.

6.1.5.3. Results

Fruit quality results are presented in Table 65 and in Plate 24.

Table 65 Acoustic firmness, weight loss, severity of lenticel spotting, skin browning, body rots, and off-odour, and percentage of saleable fruit on ripe Calypso™ mango treated with different coatings after harvest.

Coating	Acoustic Firmness (Aweta)	Weight Loss (%)	Lenticel spotting (0-4)	Skin browning (0-4)	Body Rots (0-4)	Off-Odour (0-3)	Saleable fruit (%)
No coating	12.8 ^{b}	3.9 ^{a}	2.9 ^{a}	2.4 ^{a}	0.03 ^{bc}	1.2 ^{b}	24
Carnauba wax	14.3 ^{ab}	0.8 ^{b}	2.3 ^{b}	1.7 ^{bc}	0.35 ^{a}	2.6 ^{a}	59
Polyethylene wax	17.4 ^{a}	0.0 ^{c}	2.6 ^{ab}	2.1 ^{ab}	0.33 ^{ab}	2.2 ^{a}	29
Beeswax	17.7 ^{a}	0.0 ^{c}	2.9 ^{a}	2.0 ^{ab}	0.00 ^{c}	2.0 ^{a}	35
Bio cover	15.1 ^{ab}	0.0 ^{c}	2.8 ^{a}	1.5 ^{c}	0.03 ^{bc}	2.5 ^{a}	41
**LSD	3.5	0.46	0.43	0.50	0.31	0.7	

Results are the means of 17 fruit per treatment.

Means within columns with different letters are significantly different ($P \leq 0.05$) as tested by least significant difference (LSD).

Saleable fruit (%) = percent of fruit with a severity rating below 3 for lenticel spotting or skin browning, or 1 or below for rots, or when the sum of defect ratings was 4 or below.

All treatments reached the eating soft stage at about 17 days after harvest as assessed by hand firmness, suggesting little effect of coatings in extending shelf life. However, control fruit were slightly softer than the other treatments when measured by acoustic firmness.

Carnauba wax significantly reduced lenticel spotting and skin browning compared with no coating. The other coatings did not reduce lenticel spotting compared to no coating. Bio cover also reduced skin browning compared with no coating, but the other waxes had no effect. Body rots increased with carnauba and polyethylene wax compared with no coating.

Carnauba wax had the highest percentage of saleable fruit compared with all other treatments, mainly because of the lower lenticel spotting and skin browning severity.

As expected, all coatings reduced weight loss, but appeared also to result in increased off-odours. There were no treatment effects on days to ripe (average of 17), skin colour (average of 6.0), stem end rot (average of 0.4), Brix (average of 12.9^{o} or acidity (average of 0.094%).

Overall, results suggest that coatings may help reduce severity of lenticel spotting and improve external appearance. This could justify further investigations next season, possibly with fruit from different locations and ripened after cold storage, as well as possible new coatings. Potential undesirable effects (such as increased off-odours or rots) should be assessed in more detail.

6.1.5.4. Conclusions

- The percentage of saleable fruit with carnauba wax treatment was significantly higher than the other treatments, due to less lenticel spotting and skin browning. This indicates some potential to improve external appearance.
- Fruit treated with the bio cover and the carnauba wax had less skin browning than uncoated fruit.
- As expected, all coatings reduced weight loss, but also increased off-odours.
- Coatings had little benefit in extending shelf life, since all treatments ripened at about 17 days after harvest.
- Coatings had no effect on flesh Brix or acidity at eating soft.
- Considering the potential effect in reducing the severity of lenticel spotting, further investigation next season is warranted.

No coating

Carnauba

Bio cover

Polyethylene

Beeswax

Plate 24 Calypso™ mango fruit appearance at eating soft, after coating with several surface coatings.

6.2. Retail outturn quality

6.2.1. Introduction

The production and sale of Calypso™ mango is relatively new in Australia since the variety was only commercialised in 1999 and it has taken some time to establish orchards and get sufficient quantities of fruit to market. The successful commercialisation of any new fruit variety requires high quality product to be available at the retail level for as long a period each year as possible. Fruit production for the supply chain has been developed through planting Calypso™ trees in environmentally different regions to ensure that a continuity of fruit is available for the length of the Australian mango season (Table 67). However, there is currently no information on the respective Calypso™ fruit quality and its interaction with transport, ripening and distribution infrastructure and their impact on retail shelf quality. A retail outturn assessment program to evaluate Calypso™ fruit quality at the point of sale was developed over the life of the project. Preliminary data was collected during the 2006/07 market season, however protocols lacked sufficient rigour to collect information that was suitable for use as diagnostic material for the other components of the supply chain. Improved protocols were developed for the 2007/08 season that produced useful data to assist with supply chain management.

6.2.2. Materials and Methods

The following plans were developed to assess on shelf quality:
The retail outturn assessment program was initially based on evaluation of trays of Calypso™ fruit in Woolworths and Coles stores in the capital cities of Brisbane and Melbourne. Stores at each location were to be selected at random for assessments with a sample size in each city to give a representative result for the product. For the 2007/08 fruiting season the numbers of retailer stores planned to be sampled are listed in Table 66.

Table 66 Fruit assessment plan by month and retailer.

Month	**Retailer***	
	Coles	**Woolworths**
November	20 stores	30 stores
December	10 stores	15 stores
January	10 stores	15 stores
February	20 stores	30 stores

*Based on 60/40 split of sales to Woolworths/Coles. Sales months of November & February being double the volume of January & December and so receiving double the assessments.

The sample population of trays to be assessed was 0.1% of the projected annual sales figure. Since the objective was to get data that relates to how consumers feel about the product "lay persons" were to be recruited to carry out the in-store assessments using a scoring sheet that rates external blemishes (lenticel spotting, skin browning and disease) and ripeness of the fruit. An overall appearance of the fruit on shelves was also rated. Assessments were made based on the percentage of fruit in the sample tray that met the following basic criteria:

1. What percentage of fruit in the tray is classed as 1st Grade fruit?
    a. No significant spotting?
    b. No large dents, bruises or skin marks?
    c. No uneven shape or other deformities?

2. What percentage of fruit in the tray is considered ripe and ready to eat today?

Assessments were to be carried out during the morning of each day to ensure that shelves were well-stocked with product. Only trays classed as first grade were to be examined. Completion assessment sheets were forwarded to the Quality Assurance team at One Harvest for collation and analysis. The sampling period was to be from November to February ensuring that it captured data relating to all major production areas (Table 67).

Table 67 Calypso™ mango production districts and maturity times for when fruit will be available on retail shelves.

Growing region	Sample times at retail outlets
Darwin, NT	October/November
Katherine & Mataranka, NT	November/December
Dimbulah, northern QLD	December/January
Bundaberg and Childers, southern QLD	January/February
Casino, northern NSW	February/March

6.2.3. Results

Only limited surveys were conducted because of work pressures and resignation of the key One Harvest member. However, 22 assessments were made in stores in Brisbane, Cairns and Melbourne. Of the 3180 fruit assessed, 14% had unacceptable lenticel spotting, 17% had blemishes and bruises, 12% were under-ripe and 3% had rots. Of the 15 assessments where additional comments were made, five of these stated that the fruit were over-ripe. These results confirm that lenticel spotting and skin marks, as well as over-ripe fruit are the main factors reducing the appearance of the fruit on the shelf.

Consistent feedback of poor quality fruit on the Darwin and Katherine shelves resulted in the supply chain being truncated with fruit being taken directly from local packhouses to a ripening facility in Darwin and then directly distributed to local retail outlets. This resulted in a very significant improvement in fruit quality on the retail shelf and positive comments from local consumers.

7. Transport and storage systems to optimise market returns

7.1. Fruit selection for export

As a general principle, fruit quality is determined at harvest and all procedures from harvest to consumption, with the exception of ripening in climacteric fruit, can result in quality loss. A clear understanding of practices that can reduce quality is required in order to consistently meet customer/consumer requirements.

We used a Hazard Analysis format to carefully evaluate all harvest-retail practices that can affect quality. We considered practices in the order in which they are undertaken, what quality parameters can be reduced and why, and recommendations to minimise quality loss. During the analysis, we provided recommendations for differing supply chain scenarios, for example longer distance from farm to the domestic market, export, and the need for extended storage periods to address market fluctuations.

This analysis (see Appendix 1) provides guidelines for production and postharvest requirements to meet several markets, and can also be used to aid in selection of fruit for these markets by comparing the recommended practices against those under which the crop was produced and handled.

Some of the recommendations from this hazard analysis are still under consideration.

7.2. Cold storage

7.2.1. Introduction

Cold storage regimes for Calypso™ mango were studied to identify optimum conditions for long term storage/transport. Treatments were based on our experience with 'Kensington Pride'. A short ethylene treatment after removal from storage was tested to try to eliminate the often-observed high acidity in ripe, cold stored mango.

In addition, in November 2006 one commercial Calypso™ consignment from Katherine had considerable flesh discoloration around the seed. For this consignment, evidence suggested up to three days delay between harvest and placing at low temperature, and excess time in the system. We attempted to replicate these symptoms in Calypso™ fruit from southeast Queensland to identify causal factors.

7.2.2. Materials and methods

7.2.2.1. Harvesting and treatments

Commercially picked and packed Calypso™ mango fruit were obtained at the end of the packing line from three farms in southeast Queensland on 1 February 2007, as described in Table 68. Each farm was considered a replication for statistical purposes.

Table 68. Origin, harvest and collection dates, postharvest treatment, and percent dry matter (DM) of the fruit samples used in this trial.

Farm	Harvest	Collection from farm	Fungicide treatment	**DM (%)**
1	31 Jan	1 Feb	Cold Sportak® spray	17.6
2	1 Feb	1 Feb	Cold Sportak® spray	16.0
3	30 Jan	1 Feb	Hot Spin Flo® dip	17.1

Fruit were transported to the laboratory within five hours of collection from the farm. The fruit within each replication were randomised, and arbitrarily assigned to each of the storage treatments within eight hours of collection.

Two trays of fruit (10-12 fruit per tray) per farm (replication) were held at either 8, 10 or 12°C for either three, four or five weeks. At the end of storage, one tray per replication was ripened at 20°C without ethylene, and the other tray treated with 10 ppm ethylene at 20°C for 1.5 days before holding at 20°C until ripe. This experimental design represented a three way factorial experiment, consisting of three storage temperatures, three storage durations, and two ethylene treatments. An additional tray of fruit per grower was ripened at 20°C without storage, and are referred to as control fruit.

In addition, to try to replicate symptoms of flesh discolouration, one tray of fruit per grower was held for 0, 1, 2 or 3 days at ambient temperature (around 25-28°C), then stored at 14°C for one or four weeks. Trays were removed from cold storage, and ripened at 20°C.

7.2.2.2. Quality assessment

At removal from storage, fruit firmness was assessed by gentle hand pressure using the scale in Table 69. Firmness was also assessed using the Aweta Acoustic Firmness Tester, which measures the change in frequency as sound waves are transmitted through the fruit. The technique is rapid and non-destructive, and three readings were taken around each fruit and the results averaged per fruit.

Table 69. Rating systems for fruit firmness, lenticel spotting, skin browning, body rots, stem end rots, skin chilling damage and flesh discoloration of Calypso™ mango.

Rating	Hand firmness	Area of the skin or flesh affected	
		Lenticel spotting	Skin browning, rots, skin chilling damage, flesh discolouration
0	Hard	Nil	Nil
1	Rubbery	To 10%	To 3cm^2
2	Sprung	To 25%	To 6 cm^2
3	Soft	To 50%	To 25%
4	Very soft	> 50%	> 25%

Lenticel spotting, rots, skin browning, skin chilling damage were measured using the scales in Table 69. The background skin colour was rated using the following scale: 1=0-10% yellow, 2=10-30% yellow, 3=30-50% yellow, 4=50-70% yellow, 5=70-90% yellow, and 6=90-100% yellow. The rating refers to the percentage of the background skin colour area showing yellow and not the percentage of the whole skin area.

Fruit were regularly assessed for firmness during ripening by hand and with the Aweta unit. The days to ripe were recorded as the number of days from removal from cold storage, to a firmness of three. When most fruit in each tray had reached the ripe stage, skin colour, the severity of lenticel spotting, skin browning, body rots, stem end rots, and skin chilling damage were assessed (Table 69). The cheeks were removed, and flesh colour about 5 mm in from the skin was recorded using a Minolta colour meter. Colour was recorded as Hue angle, with a lower value representing a more yellow colour. The fruit was cut open longitudinally as close to the seed as possible, and flesh discolouration (see Plate 26) was visually rated as described in Table 69, based on the surface area of the flesh affected. For Brix and acidity of the ripe flesh, subsamples of flesh were taken from 8-10 representative fruit within each replication and treatment, and fruit samples pooled to provide one sample per replication. Brix was assessed using an Atago refractometer with temperature correction. Acidity (expressed as % of citric acid) was determined by mixing each combined sample with an electric hand held blender. Five grams of the blended sample were diluted with 75 ml of distilled water before analysis using a Metrohm Titration system.

Fruit were assessed as having lost saleability if they had a rating above 0 for rots (that is, any rots) or a rating above 2 for skin browning or lenticel spotting. The results are expressed as the percentage of fruit that had lost saleability.

7.2.3. Results

7.2.3.1. At removal from storage

Both methods of measuring firmness (hand and Aweta) detected similar treatment responses, although the Aweta was less effective in detecting treatment differences in firm fruit (8°C for different storage times).

On removal from cold storage, fruit were softer with increased storage duration at all storage temperatures, and with increasing temperature after five weeks storage (Table 70). There was little effect of storage temperature on firmness at three and four weeks.

There was more yellow colour on the skin with higher storage temperatures (Table 70). Similarly, the percentage of yellow colour was higher with increasing storage duration (particularly at 12°C), but there was little increase at 8°C. In most instances, the skin colour was not attractive because of the mottled yellow/green colour, typical of that observed in the early stages of transition from green to yellow even without storage.

Fruit were sprung after four weeks at 10°C, but also well coloured. The fruit were almost ripe after five weeks at 12°C, which explains the nil effect of ethylene on this treatment (Table 70).

There were significant treatment differences in lenticel spotting at removal (Table 70). Severity was less with longer storage (particularly five weeks) at all storage temperatures. Within each storage duration, the effect of storage temperature was inconsistent. However after five weeks storage, lenticel spotting severity was considerably less at 10 and 12°C compared with 8°C.

There were no body rots on fruit at removal from cold storage for any temperature or duration (data not presented). There was relatively little stem end rots after three weeks storage at all storage temperatures, and at 8°C, there was very little stem end rots at removal for all durations (Table 70). However, stem end rots severity increased after four and five weeks storage at 12°C, and after five weeks at 10°C.

Skin browning severity decreased with increased storage time (Table 71), but there was no effect of storage temperature on severity (data not shown).

Chilling injury was not very evident just after removal, but became more obvious as the fruit ripened. There were indications of increased severity (Table 71) with longer storage, but there was no significant temperature effect.

7.2.3.2. At ripe

With no ethylene treatment, the fruit ripened more quickly when held at higher cold storage temperatures and for longer times (Table 72). Ethylene treatment decreased ripening time for the 10 and 12°C, three-week treatments, compared with no ethylene treatment. There was no further effect of ethylene treatment at four or five weeks storage for all storage temperatures.

The average ripening time in the control (non-stored) fruit, following two days of ethylene exposure, was 7.7 days. Fruit from Farm 3 ripened quicker (five days) than fruit from the other two farms (nine days). This suggests that cold storage a small effect on ripening time.

The treatment effects on skin colour of the ripe fruit were relatively small (Table 72; Plate 25) and would likely have little commercial impact. With no ethylene treatment, there was more yellow colour on the ripe skin of the 8°C storage treatment after five weeks compared with three and four weeks, but with 12°C storage, there was more yellow after five weeks storage compared with three weeks storage. This suggests an inconsistent/small effect of these storage conditions on skin

colour, and again confirms the robust nature of attractive skin colour development in Calypso™ mango.

Table 70. On removal from storage: Effect of storage temperature and duration on fruit firmness (using hand assessment and the Aweta acoustic firmness tester), skin colour, lenticel spotting and stem end rots of Calypso™ mango. For each fruit characteristic, mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by least significant difference (LSD).

Storage duration (weeks)	Storage temperature (°C)		
	8	10	12
Aweta firmness			
3	37.1 ab	34.9 b	30.1 cd
4	35.1 b	31.2 c	21.9 e
5	38.1 a	28.0 d	23.3 e
Hand firmness (0-4)			
3	0.3 f	0.3 f	0.5 f
4	1.4 d	1.0 e	1.5 d
5	1.8 c	2.5 b	2.8 a
Skin colour (1-6)			
3	2.1 e	3.3 c	3.8 b
4	2.3 de	3.3 c	4.1 b
5	2.6 d	3.8 b	5.2 a
Lenticel Spotting (0-4)			
3	2.8 a	2.1 bcd	2.4 bc
4	2.1 cd	2.2 bcd	2.4 b
5	2.0 d	1.3 e	1.4 e
Stem End Rots			
3	0.00 d	0.06 d	0.00 d
4	0.00 d	0.07 cd	0.33 ab
5	0.01 d	0.54 a	0.27 bc

Table 71. On removal from storage: The effect of storage duration on skin browning and skin chilling injury. The results are averaged across the three storage temperatures since there were no significant interactions between storage duration and temperature. Within each column, mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Storage duration (weeks)	Skin browning (0-4)	Skin chilling damage (0-4)
3	0.5 a	0.0 b
4	0.4 ab	0.0 b
5	0.3 b	0.1 a

In most instances, ethylene treatment had either no effect, or improved the ripe skin colour, compared with no ethylene treatment (Table 72). The only exception was the 8°C, five-week treatment, where ethylene reduced the percentage of yellow colour on the ripe skin compared with no ethylene treatment.

The control (non-stored) ripe fruit (following two days of ethylene treatment) were fully yellow (no green colour; rating 6) when ripe.

Table 72. At ripe: Effect of storage temperature and duration, and ethylene treatment after removal from storage on the days from removal to ripe, skin colour and flesh colour of Calypso™ mango. For each fruit characteristic, mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Storage Temp (°C)	Storage duration (weeks)					
	3		4		5	
	Eth	No eth	Eth	No eth	Eth	No eth
Days to ripe						
8	8.0 [a]	8.0 [a]	7.0 [d]	7.7 [b]	7.0 [d]	7.0 [d]
10	7.3 [c]	7.9 [a]	7.0 [d]	7.3 [c]	6.3 [f]	6.3 [f]
12	6.7 [e]	7.3 [c]	6.0 [g]	6.0 [g]	5.7 [h]	5.7 [h]
Skin colour at ripe (1-6)						
8	5.6 [cdef]	5.6 [def]	5.5 [ef]	5.5 [ef]	5.4 [f]	5.8 [abc]
10	5.8 [abcd]	6.0 [a]	5.7 [bcde]	5.4 [f]	5.8 [abcd]	5.8 [abcd]
12	5.8 [abcd]	5.9 [ab]	5.9 [ab]	5.9 [ab]	5.8 [abcd]	5.5 [ef]
Flesh colour at ripe (Hue angle)						
8	92.8 [bcd]	92.4 [cde]	95.1 [a]	93.3 [b]	94.5 [a]	93.4 [b]
10	91.5 [f]	90.4 [g]	92.2 [cdef]	91.8 [ef]	92.7 [bcd]	92.9 [bcd]
12	92.1 [cdef]	91.5 [f]	92.1 [cdef]	92.5 [cde]	92.9 [bc]	92.1 [def]

The ripe flesh was less yellow (lower Hue values indicate more yellow colour) with longer storage times at all storage temperatures, with the biggest decrease in flesh colour occurring between three and four weeks (Table 72). Generally, 10°C storage resulted in the most yellow flesh colour, and 8° storage with the least yellow flesh colour. In some cases, ethylene treatment resulted in less yellow colour, probably because these fruit ripened more quickly, with less time for yellow colour development.

Lenticel spotting was very severe this season in fruit from all three growers, even without storage. For example, the average ratings for lenticel spotting in the control (non-stored) fruit was 1.6. Fruit from Farm 3 had less lenticel spotting (rating of 0.4) than fruit from Farm 1 (2.0) and Farm 2 (2.3). High lenticel spotting severity was also noted on 'Kensington Pride' in other growing regions around Australia this season (Greg Owens, personal communication).

With no ethylene treatment, lenticel spotting was lower with 10°C storage compared with 8 or 12°C (Table 73). With ethylene treatment, 10 and 12°C fruit had the lowest lenticel spotting. With12°C storage, ethylene treatment reduced lenticel spotting, and a similar trend was observed at 10°C.

There was no effect of duration on lenticel spotting severity (results not presented).

There was little effect of increasing storage temperature on skin browning severity in ripe fruit (Table 74). Skin browning increased with increasing storage time, and particularly between three and four weeks storage. This was observed at all storage temperatures. It is possible that other defects masked any changes in skin browning with longer duration, however results from the previous Calypso™ project also confirmed less skin browning in sprung fruit held at 10°C for seven days.

There was no effect of ethylene on skin browning (results not presented).

There was very little skin browning in the control (non-stored) fruit (data not presented).
This was first noted as a significant issue in a commercial consignment from Katherine in November 2006. In the present trial, there was no evidence of flesh discoloration after three weeks of storage at any storage temperature (Table 74). However, severity increased with longer storage time, particularly at 8 and 10°C. This suggests that flesh discoloration may be associated with

inappropriate cold storage conditions, but other factors such as delays between harvest and the start of storage may also be contributing factors.

There was no effect of ethylene on flesh discolouration (results not presented).

Table 73 At ripe: Effect of storage temperature and ethylene treatment on lenticel spotting severity (zero = none; 4 = severe) of ripe Calypso™ mango. Mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Ethylene	Temperature (°C)		
	8	10	12
No	3.0 [a]	2.4 [c]	2.8 [b]
Yes	3.1 [a]	2.2 [cd]	2.0 [d]

Table 74 At ripe: Effect of storage temperature and time on skin browning and flesh discolouration of ripe Calypso™ mango. For each fruit characteristic, mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Storage time	Storage temperature (°C)		
(weeks)	**8**	**10**	**12**
Skin browning (0-4)			
3	1.1 [a]	0.7 [bc]	1.1 [a]
4	0.7 [bc]	0.9 [ab]	0.8 [bc]
5	0.7 [bc]	0.6 [c]	0.6 [c]
Flesh discolouration (0-4)			
3	0.0 [c]	0.0 [c]	0.0 [c]
4	0.2 [bc]	0.4 [b]	0.4 [b]
5	0.8 [a]	0.7 [a]	0.3 [b]

No evidence of flesh discolouration was found in ripe fruit from the extra trays used to try to simulate the disorder (data not shown). These fruit had been held at room temperature for 0, 1, 2, or 3 days then held for one or four weeks at 14oC before ripening.

Body rots severity increased with higher storage temperatures (Table 75). In contrast, stem end rots severity decreased from 8 to 10°C storage, but there was no difference between 10 and 12°C.

Both body and stem end rots severity increased with increasing storage times, particularly between three and four weeks storage.

There was no ethylene effect on body or stem end rots severity (data not presented).

The average ratings for stem rots in the ripe, control (non-stored) fruit was 0.4. Fruit from Farm 3 had less stem end rots (rating of 0.2) than fruit from Farm 1 (0.7) and Farm 2 (0.4). There was virtually no body rots in the control fruit.

There was no effect of temperature on skin chilling damage severity (Table 75). Chilling damage was higher after five weeks storage compared with four weeks.

On average across all treatments, about 80% of the stored fruit lost saleability. The major factors were the high lenticel spotting severity (about 50%) and rots (about 26%). The 10°C storage treatment had the least effect on saleability (the lowest loss of saleability) compared with 8 and 12°C (Table 75). The increased loss of saleability at 8°C was mostly due to increased rots and lenticel spotting, and at 12°C, due to increased lenticel spotting. There was practically no difference in loss of saleability between farms (replications).

Table 75 At ripe: Effect of storage temperature and storage time on body rots, stem end rots, external chilling damage and loss of saleability of ripe Calypso™ mango. For each fruit characteristic, mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Treatment	Body rots (0-4)	Stem end rots (0-4)	Skin chilling damage (0-4)	Loss in saleability (%)
Temperature (°C)				
8	0.4 [b]	0.9 [a]		91.4 [a]
10	0.4 [b]	0.6 [b]		70.7 [b]
12	0.5 [a]	0.6 [b]		78.8 [b]
Time (weeks)				
3	0.2 [c]	0.4 [b]	0.2 [b]	73.7 [b]
4	0.5 [b]	0.7 [a]	0.2 [b]	82.3 [ab]
5	0.6 [a]	1.0 [a]	0.6 [a]	84.8 [a]

Saleability also decreased with increased storage duration, primarily because of increased rots and chilling injury to the skin.

The high loss of saleability was due more to the inherently ”lower” fruit quality this season, rather than the storage treatment itself. For example, even with no storage (control fruit), the loss of saleability was 47%, mainly due to lenticel spotting (about 22%) and stem end rots (about 33%). In contrast with stored fruit, control fruit had larger differences between farms for loss of saleability: fruit from Farm 3 had a lower loss of saleability (16%) compared with fruit from Farm 2 (58%) and Farm 1 (67%). However, fruit from Farm 3 were more yellow on arrival and ripened quicker than fruit from the other farms.

Acidity was higher in the ripe flesh after 8°C storage, compared with 10 and 12°C (Table 76). Also, acidity was higher with four and five weeks storage, compared with three weeks storage.

Ethylene treatment after removal from cold storage increased acidity in the ripe fruit, compared with no ethylene treatment. This suggests that the ethylene treatment accelerated fruit softening more than the decrease in acidity.

The average Brix in the ripe flesh across all treatments was 15.1°, and there was no treatment effect on ripe flesh Brix.

Table 76 At ripe: Effect of storage temperature, storage time and ethylene treatment after removal from cold storage on the acidity (expressed as % citric acid) of the ripe Calypso™ mango. Mean values followed by different letters are significantly different ($P \leq 0.05$) as tested by LSD.

Treatment	Acidity (% citric acid)
Temp	
8	0.276 [a]
10	0.202 [b]
12	0.193 [b]
Time	
3	0.190 [b]
4	0.241 [a]
5	0.240 [a]
Ethylene	
No ethylene	0.185 [b]
Ethylene	0.262 [a]

Storage temperature			Storage duration
8°C	10°C	12°C	
			3 weeks
			4 weeks
			5 weeks

Plate 25 Typical appearance of ripe Calypso™ mango fruit following storage at 8, 10 and 12°C for three, four or five weeks. Photos are fruit from the same farm (no ethylene treatment)

Typical chilling injury, with moderate to severe lenticel spotting

Dendritic spot Stem end rots

Symptoms of flesh discolouration

Plate 26 Defects on Calypso^{TM} mango following cold storage

7.2.4. Conclusions and recommendations

Lenticel spotting severity was particularly high this year, and to some extent "clouded" the results. Also, rots were common, but this was expected given that fruit were obtained from wet production areas. Nevertheless, useful results were obtained which will form the basis for research next year on fruit from drier production locations.

On removal from cold storage:

The fruit had about 50% yellow colour on removal, but were still relatively firm. Higher temperatures and longer durations resulted in more yellow colour and softer fruit.

There was no consistent effect of temperature or duration on lenticel spotting severity. However, it was obvious that with five weeks storage, 8°C resulted in more lenticel spotting than at 10 or 12°C.

Skin browning severity was not affected by temperature, but was less with longer storage.

At ripe:

As expected, the ripening time after removal from cold storage decreased with increased storage temperature and duration, but was still relatively good (6-8 days). Ethylene treatment had little effect on ripening time.

Most fruit had more than 90% yellow skin colour at ripe, but did not attain the attractive, full yellow skin colour associated with non-stored fruit. Generally, 8°C storage resulted in the least yellow skin colour.

Storage at 8°C resulted in higher lenticel spotting severity compared with 10°C, and there were indications of less skin browning at 10°C.

Body rots severity was higher at 12°C, and stem end rots higher at 8°C. Overall, the lowest rots severity occurred at 10°C. Also, rots severity increased with increased storage time.

About 75% of the fruit had lost saleability after three weeks storage mainly from lenticel spotting and rots. However, even without storage, the loss of saleability was high (47%), suggesting inherently less “robust” fruit this season. The loss of saleability was highest at 8°C but there was little difference between 10 and 12°C. Loss of saleability increased with longer storage times.

Brix was not affected by storage temperature or storage time.

Flesh acidity was higher with 8°C storage compared with 10-12°C, and was also higher with storage for four weeks or longer. Ethylene treatment after removal from cold storage increased flesh acidity compared to no ethylene treatment, which was opposite to expectations. However, these treatment effects on acidity are unlikely to affect flavour.

Flesh discolouration:

Some flesh discoloration (similar to that observed in commercial consignments from Katherine this season) was noted during the main cold storage trial, with severity increasing with five weeks storage, and at lower temperatures. To try to understand the causes of this disorder, additional fruit were held for 0-3 days at room temperature to allow slight ripening, then held at 14°C for one and four weeks. None of these the treatments resulted in this disorder being expressed.

The results suggest 10-12° as the best storage temperature for Calypso™ mango. At lower temperatures lenticel spotting and stem end rots can be higher.

Further cold storage trials should be conducted next year using fruit from dry production locations. These trials should link in with any commercial export trials.

7.3. Controlled and modified atmosphere storage

7.3.1. Controlled atmospheres export trial

7.3.1.1. Introduction

Considerable CA research has been conducted in mango (Johnson and Hofman 2009), including 'Kensington Pride'(McLauchlan and Barker 1994) Most of the results suggest atmospheres of about 2% O_2 and 5% CO_2, and it is likely that Calypso™ would perform well under these conditions also.

One Harvest decided to include several pallets of Calypso™ mango in a CA container with 'Kensington Pride' destined for Holland, using the above atmospheres and 12°C storage temperature. We monitored the outturn quality of these fruit, and also held the same fruit under the same temperatures and O_2 concentrations in the laboratory. The storage potential of fruit from several locations was also compared, as well as the effect of Smartfresh℠.

7.3.1.2. Materials and methods

7.3.1.2.1. Fruit and treatment

Calypso™ fruit were commercially harvested from Oolloo Farms Darwin on Wednesday morning 7th November. The fruit were transported to Katherine in 450 kg bins via Darwin, using a one tonne utility then a non-airbag suspension truck. The fruit were accidentally exposed to heavy rain from Darwin to Katherine (This was a specific trip for the trial fruit since it was difficult to get other transport for the two bins). The fruit arrived at Katherine at 7.00 pm and were packed and placed under forced air at 12°C by 9:30 p.m. Temperature loggers were placed in fruit during palletising.

'Kensington Pride' fruit were obtained from King Producers Pty Ltd Katherine. The fruit were harvested on Tuesday 6th November and cooled overnight to 14.6°C prior to packing on Wednesday 7th November.

About 1.00 pm the following day the fruit were placed into plastic tents at 12°C and treated with either 625 (Low) or 1000 (High) ppb of 1-methylcyclopropene (1-MCP) as the commercial formulation SmartFresh℠ for 24 hr. Similar fruit were placed in a separate plastic tent in another cold room in the absence of SmartFresh and also held for 24 hrs (control). Activated lime was placed in each tent to reduce CO_2 accumulation.

The fruit were removed from the tent after 24 hrs for the following trials:

7.3.1.2.2. Seafreight

Twelve trays from each treatment were taken to King Producers at about 6.30 am on Friday 9th November for placing on a pallet for seafreight to the Netherlands. The container was pre-cooled to 12°C, and the fruit loaded into the container by late afternoon. The container was sealed, transported to Darwin and atmosphere control commenced by Saturday morning. Controlled atmosphere (CA) conditions of 2% O_2 and 3% CO_2 at 12°C were used initially, then after several days the CO_2 concentration set at 5% and temperature at 11.5-12°C to stabilise respiration.

The container was shipped from Darwin on Tuesday 13th November and arrived at Amsterdam on Thursday 13th Dec (see Table 77). Fruit were assessed on removal on Tuesday 18th, then three trays of each treatment held at room temperature and assessed every few days by Agrofresh colleagues in the Netherlands (see below).

Table 77 Summary of fruit treatment/movements

Date	Activity	Comments
7th Nov	Calypso™ fruit for SmartFresh trial picked and packed	
8th Nov	Fruit treated with SmartFresh.	
	Fruit for the other four Calypso™ pallets (for commercial sale etc) picked and packed.	
9th Nov	SmartFresh treatment terminated. Some fruit airfreighted to Brisbane and placed under static CA and cold storage.	
	Remaining SmartFresh fruit and additional four pallets packed into CA sea container.	
10th Nov	Container transported to Darwin and CA commenced.	
13th Nov	Container shipped to Singapore and Europe	Container due to be loaded on 10th Nov, but ship delayed. Connection in Singapore missed. Container finally transported on Hyundai ship, resulting in 2-3 day delay in arrival in Europe
13th Dec	Ship arrived in Amsterdam	
14th Dec	Container loaded from ship	Container not released because change in shipping company in Singapore resulted in appropriate paperwork not being available.
17th Dec late p.m.	Container arrives at Green Box. Fruit removed to 20°C with ethylene.	
18th Dec	Fruit held at 20°C. Fruit quality assessed. SmartFresh samples given to AgroFresh Netherlands rep for ripe fruit quality and shelf life assessment. Fruit samples taken for residues testing.	Delays in container release required ripe fruit assessment to be done by others.
19th Dec	Calypso™ fruit rejected because of MRL breach	

7.3.1.2.3. Static trial

Trays from each SmartFresh treatment on both Calypso™ and 'Kensington Pride' were airfreighted to Brisbane the same day and placed at 11.5°C either in CA or in air (with no atmosphere modification). About 12 hrs elapsed between removal of fruit from the treatment cold room at Katherine to placement in the cold and CA rooms in Brisbane, with no temperature control during this time.

The fruit were held under 3% O_2 at 11.5°C. Activated lime maintaied CO_2 below 0.5%. Fruit were removed after three, four and five weeks of storage. External fruit quality was assessed on removal from air or CA storage. The fruit were then ripened at 20°C (no ethylene). Fruit from each treatment were assessed for quality (see below) when they reached the eating soft stage (firmness of 3). The remaining fruit were held at 20°C until the fruit were unsaleable, and the shelf life (the days from first ripe to end of saleable life) determined.

Katherine and Dimbulah

Fruit were obtained from Oolloo Farms Katherine (harvested 10th December, treatments commenced 12th December) and a Dimbulah farm (fruit harvested 7th January, placed at 12°C early 10th January, and CA treatment commenced 11th January). Fruit were held in air or under CA (3%

O_2, no CO_2) at 11.5°C and samples removed at three, four and five weeks, as above. No SmartFresh treatment was used.

7.3.1.2.4. Quality assessment

The rating scales in Table 78 were used:

Table 78 Rating scales used in quality assessment

Rating	Firmness	Lenticel spotting	Skin browning and rots
0	Hard	Nil	Nil
1	Rubbery	To 10%	To 3cm^2
2	Sprung	To 25%	To 6 cm^2
3	Soft	To 50%	To 25%
4	Very soft	> 50%	> 25%

3cm^2 is the size of a 5 cent piece
6cm^2 is the size of a 20 cent piece

For the seafreighted fruit:

Rots were rated based on the symptoms (Plate 34) rather than the possible causes. For the seafreight trial these were:

- Light coloured body rots (those occurring on the side of the fruit), which may be caused by wound pathogens such as *Rhizopus* which are more common after long term storage.
- Dark coloured body rots typical of anthracnose.
- Firm dark stem end rot generally caused by anthracnose.
- Firm light stem end rot.
- Soft dark stem end rot, which could be a progression of firm dark stem end rot, or caused by typical stem end rot fungi.

Skin browning symptoms were described as follows (Plate 34 and Plate 35):

- Abrasion; clear scratches on the skin
- Discrete; typically caused by stem contacting adjacent fruit skin during transport in bulk bins, and
- Blotch; round areas of browning, most likely caused by contact with other fruit or bin sides.
- Under skin, similar to disorder X but not sunken into the skin

The background skin colour was rated using the following scale:

1 = 0-10% yellow
2 = 10-30% yellow
3 = 30-50% yellow
4 = 50-70% yellow
5 = 70-90% yellow, and
6 = 90-100% yellow.

This rating refers to the percentage of the background skin colour (non-red) area showing yellow and not the percentage of the whole skin area.

Ratings for the static trials were as in Table 78.

Fruit were considered to be saleable if there were no rots, or other individual defects were less than severity 3, or all combination of defects had a combined rating of 4 or less. The shelf life of each

treatment was determined when most fruit (>80%) from that treatment (usually a tray) were no longer saleable.

7.3.1.3. Results

7.3.1.3.1. Seafreight

Temperatures and atmosphere

Fruit were forced-air cooled to 16-17°C pulp temperature before loading into the container (Figure 47). Pulp temperatures declined to 13-14°C over the next two days, and were maintained at these temperatures throughout the voyage. Pulp temperatures were about 1°C higher towards the door compared with closer to the refrigeration unit.

On arrival at Green Box (Netherlands), pulp temperatures were recorded at 11.5°C using several digital thermometers placed in 4-6 fruit from pallets near the door of the container. This was identical to the set temperature on the container.

7.3.1.3.2. Fruit quality

On removal

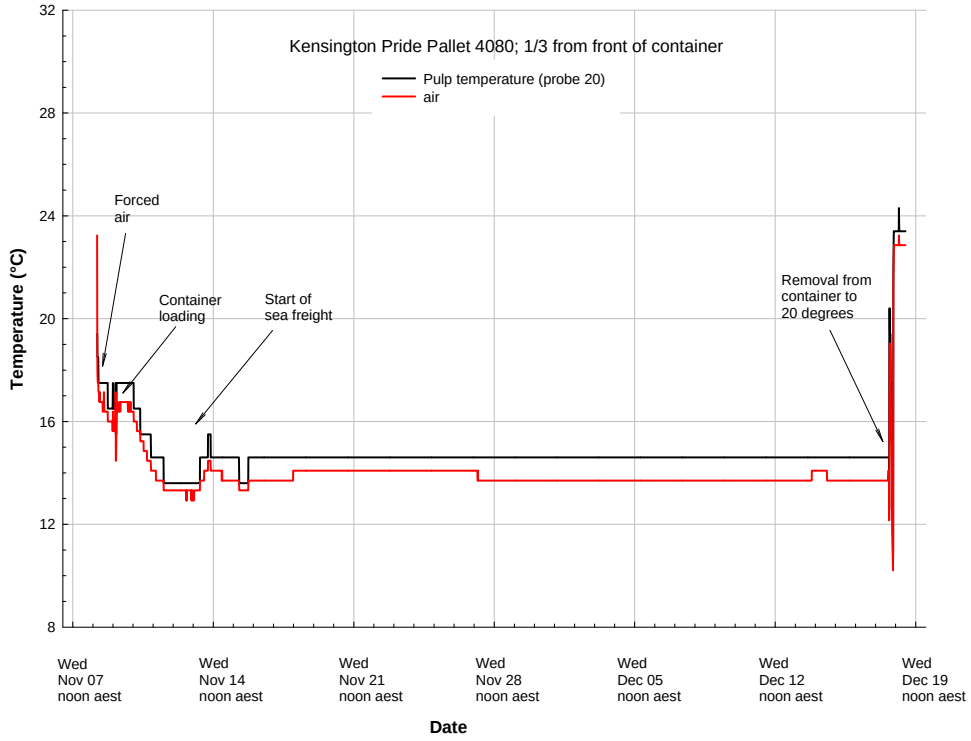
In general, fruit quality at removal was good considering the 37 days from harvest to outturn.

One day after removal from the container, Calypso™ fruit were firmer and more coloured (more yellow) than 'Kensington Pride', which is typical for each cultivar (Table 79, and Plate 27). About 3% of Calypso™ fruit had some disease at removal. Most disease was at the stem end, with some fruit in the remaining four pallets having completely collapsed with typical stem end rot symptoms. The presence of stem end diseases suggests that hot fungicide treatments should be investigated, since these are poorly controlled by cold fungicide treatments. If Spin Flo is not tolerated in European markets, then hot Sportak spray systems could be considered. There was little body rots.

Lenticel spotting severity was low at removal (Table 79). The two most notable forms of skin browning were:

- Blotch, most likely caused by fruit-fruit or fruit-bin contact during transport from Darwin to Katherine. Severity was low, but 41% of Calypso™ fruit had some level of blotch.
- Under skin browning, similar to "disorder X", but not sunken. Severity was relatively low and in most cases the discoloration was fairly light. The symptoms could become more obvious as the fruit ripened, and may be confused with disease.

In 'Kensington Pride', both stem end and body rots severity and incidence were higher than in Calypso™ (Table 79). Abrasion was by far the most common form of skin browning. This was almost absent in the remaining 'Kensington Pride' pallets, suggesting that the fruit selected for the SmartFresh trial were second grade fruit. Under skin browning was also present but not as common.



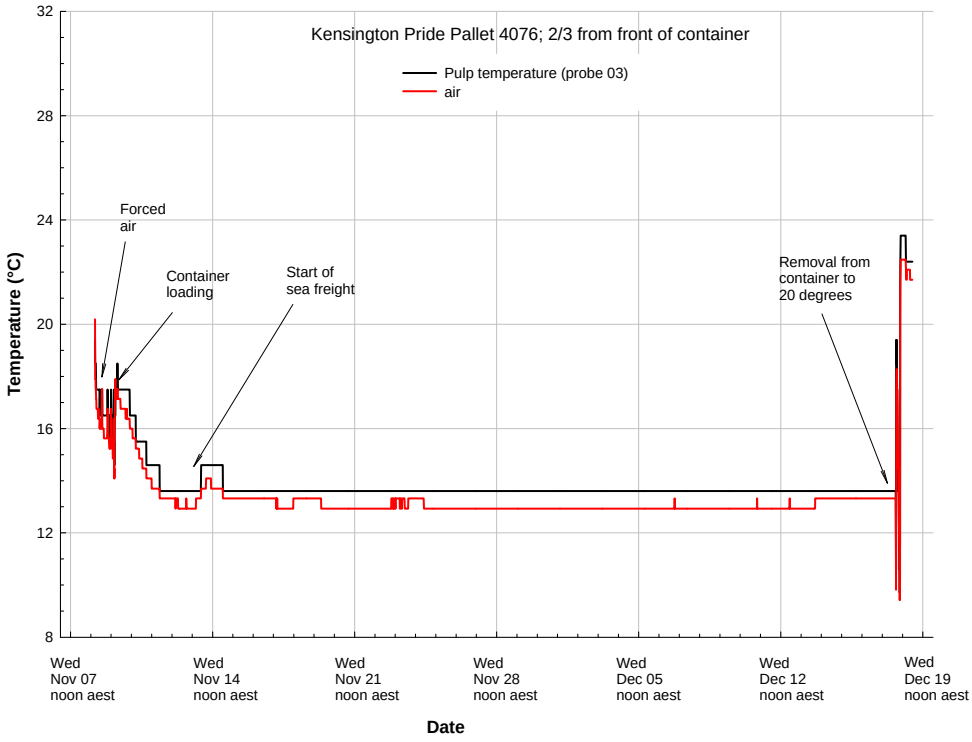
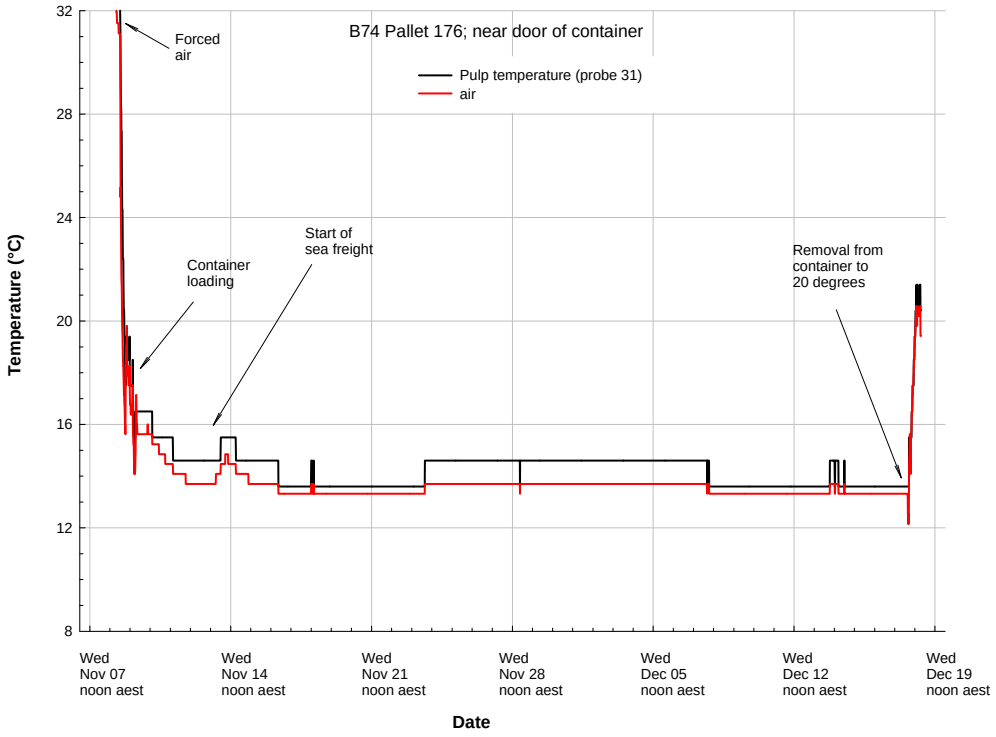


Figure 46. ‘Kensington Pride’ mango: Air and pulp temperatures recorded by four loggers placed in the fourth, seventh and 10th (at the door) row from the front of the container. Two loggers were placed in the two pallets next to the door. The loggers had an accuracy of +/-0.5°C.



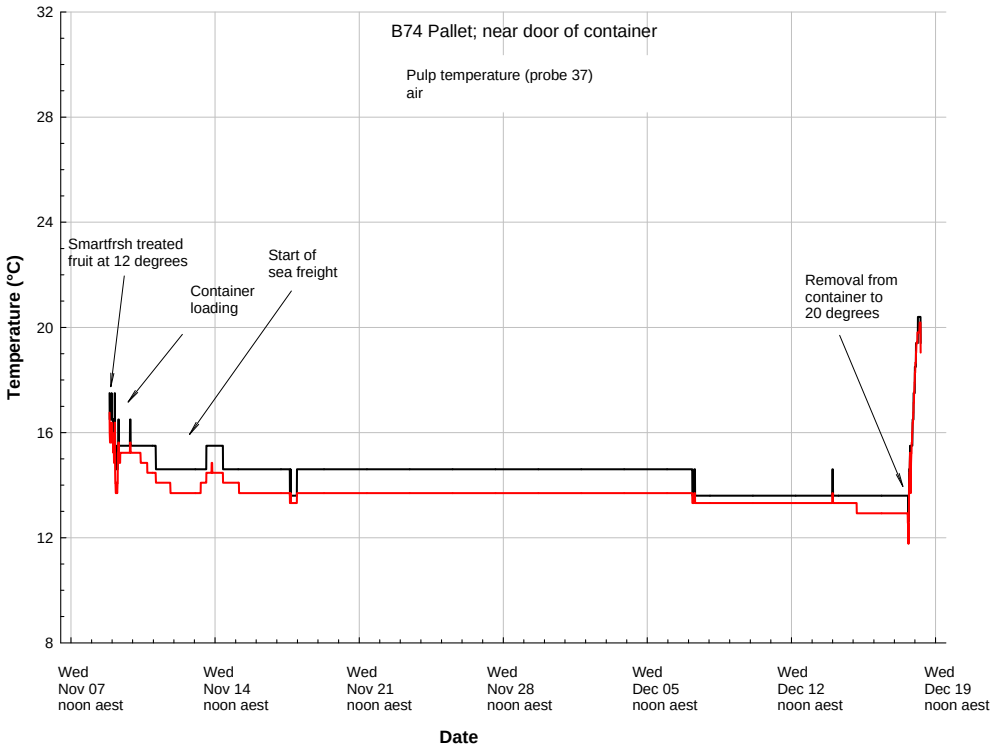


Figure 47. Calypso^{TM} mango: Air and pulp temperatures recorded by four loggers placed in the fourth, seventh and 10th (at the door) row from the front of the container. Two loggers were placed in the two pallets next to the door. The loggers had an accuracy of +/-0.5°C.

Table 79. Fruit seafreighted to the Netherlands; on removal from CA. The effect of cultivar and SmartFresh treatment on firmness, skin colour, rots, lenticel spotting (LS) and skin browning on removal from the seafreight container.

Cultivar	SmartFresh Treatment	Firmness (0-4)	Skin colour (1-6)	Rots (0-4)					LS (0-4)	Skin browning (0-4)				
				Stem			Body			Diffuse	Blotch	Discrete	Under skin	Abrasion
				Soft dark	Firm light	Firm dark	dark	light						
Average severity (0-4)														
Calypso™	Nil	2.5	4.7	0.02					0.1	0.2	0.5	0.1	0.1	
	Low	2.3	4.7							0.1	0.3		0.4	
	High	2.5	4.9						0.2	0.2	0.4	0.03	0.2	
'Kensington Pride'	Nil	3.5	3.8		0.1	0.1	0.2		0.6	0.1			0.1	1.0
	High	3.5	3.8				0.05	0.02	0.5	0.02			0.3	1.1
Incidence (% of fruit affected)														
Calypso™	Nil			3					11	19	41	11	5	
	Low									12	24		18	
	High								14	19	25	3	17	
'Kensington Pride'	Nil				5	2	7		48	5			5	71
	High				2	2	5	2	45	2			10	69

There was virtually no effect of SmartFresh on either firmness or skin colour at removal from CA in both cultivars (Table 79, Plate 27 and Plate 31). However, there were indications that SmartFresh increased the incidence of under skin browning in both cultivars.

During ripening

About 70-100% of the fruit were saleable 2-3 days after removal, but this percentage decreased rapidly with time (Figure 48). Smartfresh treatment resulted in more saleable 'Kensington Pride' fruit two days after removal, mainly because of less body rots and diffuse browning with Smartfresh treatment. There was no SmartFresh benefit after 2-3 days. Low SmartFresh treatment maintained Calypso™ saleability for five days compared with nil and high doses, but there was no benefit thereafter. The benefits of low doses in the early stages may be due to the statistically firmer fruit one day after removal, although this difference was not obvious by three days.

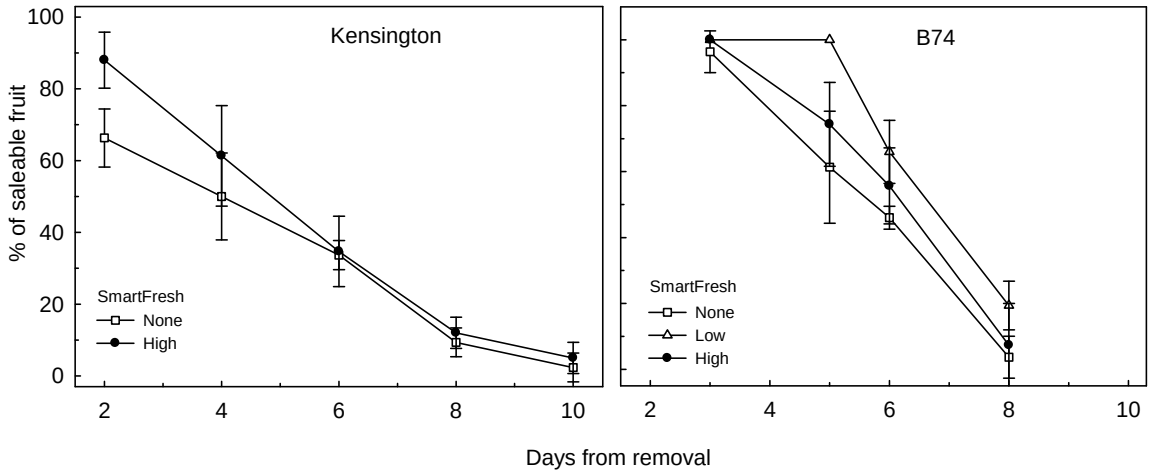


Figure 48. Fruit seafreighted to the Netherlands. The percentage of saleable 'Kensington Pride' and Calypso™ mango fruit at different days after removal from the controlled atmosphere container, and held at room temperature. Bars indicate standard errors.

There were no significant treatment effects on lenticel spotting, skin browning or rots one and three days after removal for Calypso™ mango, or two and four days after removal for 'Kensington Pride' mango (Table 80). Skin browning and lenticel spotting were the major contributors to loss of saleability for both cultivars.

Table 80. Fruit seafreighted to the Netherlands. Defects severity on Calypso™ and 'Kensington Pride' mango 1-4 days after removal from the controlled atmosphere container. Results averaged across all treatments.

Defect (0-4)	Calypso™		'Kensington Pride'	
	Days after removal		Days after removal	
	1 day	3 days	2 days	4 days
Lenticel spotting	0.15	0.40	0.57	1.09
Skin browning	0.71	1.35	0.84	1.07
Body rots	0.02	0.04	0.25	0.13
Stem end rots	0.03	0.10	0.10	0.00

7.3.1.3.3. Static Trial

On removal from storage

Calypso™

On removal, fruit were generally softer (higher hand firmness reading, lower acoustic firmness) with increased storage time (Table 81). This was not so obvious when firmness was measured by hand pressure, but was confirmed when estimating firmness using the Aweta (acoustic) system. There was no significant effect of SmartFresh on firmness. Controlled atmospheres resulted in softer fruit on removal, as has been observed in other CA trials.

There was very little effect of storage time on skin colour at removal (Table 81), suggesting that most of the loss of green colour occurred during the first three weeks of storage. Smartfresh had no consistent effect on skin colour, while CA resulted in more green colour on removal.

Table 81 Static trail. External quality of Calypso™ mango on removal from storage, following treatment with either nil or high SmartFresh concentrations, and 12°C cold storage for 3, 4 or 5 weeks either without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide).

Weeks of storage (at 12°C)	Storage treatments			
	Air		CA	
	SmartFresh		SmartFresh	
	Nil	High	Nil	High
Hand firmness (0-4)				
3	1.0 cd	1.0 cd	1.3 b	0.9 d
4	1.6 a	1.5 a	1.5 a	1.6 a
5	1.0 cd	1.2 bc	1.6 a	1.5 a
Firmness (acoustic)				
3	45.1 a	47.3 a	27.1 f	29.0 ef
4	36.3 bc	38.4 b	35.9 bc	38.5 b
5	29.6 ef	31.2 de	14.0 g	33.8 cd
Skin colour (1-6)				
3	4.9 bc	4.8 bcd	4.6 de	4.6 cde
4	4.8 bcd	4.6 cde	4.4 e	4.4 e
5	5.1 b	5.5 a	4.6 cde	4.7 cde
Lenticel spotting (0-4)				
3	1.6 ab	1.7 a	0.5 f	0.5 ef
4	1.0 cdef	1.0 def	0.8 def	1.1 bcde
5	1.8 a	1.8 a	1.1 bcd	1.5 abc
Skin browning (0-4)				
3	0.0 d	0.0 d	0.0 d	0.0 d
4	0.0 d	0.0 d	0.0 d	0.0 d
5	1.1 a	0.7 b	0.4 c	0.4 c
Physical damage(0-4)				
3	1.0 ab	0.7 bc	0.8 ab	0.4 cd
4	0.9 ab	0.9 ab	0.7 abc	1.1 a
5	0.0 d	0.0 d	0.0 d	0.0 d
Abrasion (0-4)				
3	0.0 c	0.0 c	0.0 c	0.0 c
4	0.0 c	0.0 c	0.0 c	0.0 c
5	0.4 a	0.3 ab	0.4 ab	0.2 b

Means of 17 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Lenticel spotting severity was lower following four weeks storage without CA, but severity at three and five weeks was similar (Table 81). With CA, severity increased with increased storage time. Smartfresh had no effect on lenticel spotting, while CA sometimes reduced lenticel spotting.

Skin browning severity increased from four to five weeks storage, but SmartFresh and CA had no effect on it.

'Kensington Pride'

On removal, fruit were generally softer with increased storage time (Table 82). SmartFresh resulted in firmer fruit after four and five weeks CA storage.

There was no significant effect of either storage time or SmartFresh on skin colour at removal (Table 82).

Lenticel spotting severity was higher with longer CA storage, but there was no significant effect of SmartFresh on lenticel spotting at removal (Table 82). Skin browning severity increased from four to five weeks storage, but SmartFresh had little effect on it.

Table 82 External quality of 'Kensington Pride' mango on removal from storage, following treatment with either nil or high SmartFresh concentrations, and 12°C cold storage for 3, 4 or 5 weeks with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide).

Weeks of storage (at 12°C)	SmartFresh	
	Nil	High
Hand firmness (0-4)		
3	3.2 [a]	3.1 [a]
4	2.8 [b]	2.2 [c]
5	3.1 [a]	2.5 [b]
Skin colour (1-6)		
3	4.2	4.1
4	4.3	4.4
5	4.3	4.1
Lenticel spotting (0-4)		
3	1.3 [e]	1.5 [de]
4	2.0 [bc]	1.8 [cd]
5	2.4 [a]	2.3 [ab]
Skin browning (0-4)		
3	0.1 [c]	0.0 [c]
4	0.0 [c]	0.0 [c]
5	0.4 [a]	0.3 [b]
Physical damage (0-4)		
3	0.1 [c]	0.0 [c]
4	0.9 [a]	0.6 [b]
5	0.0 [c]	0.0 [c]
Abrasion (0-4)		
3	1.3 [b]	1.0 [bc]
4	2.4 [a]	2.1 [a]
5	0.7 [cd]	0.4 [d]

Means of 28 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

At ripe external appearance

Calypso™

Smartfresh increased the days to eating soft by 4-5 days in the absence of storage (Table 83). There was no difference in days to soft between the low and high SmartFresh treatments.

Fruit ripened 4-8 days quicker with storage compared with no storage (Table 83). In some instances CA reduced the days to eating soft compared with no CA. Also, sometimes SmartFresh increased the days to eating soft by up to four days, but this did not occur in all treatments.

At eating soft, there was no significant treatment effect on skin colour (data not presented Plate 36-Plate 38), with most treatments reaching full yellow colour when ripe. There were indications that five weeks storage may result in some remaining green colour (average skin colour 5.9), particularly after CA, but this is likely to be minor issue in commercial shipments.

Lenticel spotting severity was generally high across all treatments even without SmartFresh or storage (Table 83). Smartfresh generally increased lenticel spotting, particularly with no storage and after three weeks storage. This may be associated with a longer time to ripen with SmartFresh treatment. There was little SmartFresh effect on lenticel spotting with four and five weeks storage. Controlled atmospheres sometimes reduced lenticel spotting compared with no CA, but this was not consistent.

Body rots severity was very low or absent across all treatments (Table 83). There was little consistent effect of treatment on body rots severity, except that severity increased with longer storage times. There was very little dendritic spot or stem end rots, and there were no significant treatment effects on these diseases. The occasional fruit that had stem end rots were usually badly affected.

Skin browning severity was reduced with three weeks storage compared with no storage (Table 83). Similar results have been obtained in previous work with shorter storage durations. With increased storage times, skin browning severity was similar to severity with no storage. There was little consistent effect of SmartFresh on skin browning severity, and severity was often lower with CA in the absence of SmartFresh treatment.

The percentage of saleable fruit was based on only eight fruit per treatment, so results were variable, and no statistical analysis was possible. Typically 25-50% of the fruit were not saleable, mainly because of lenticel spotting and skin browning. There was no consistent effect of SmartFresh or CA on the percentage of saleable fruit.

Saleability could be increased by consuming the fruit earlier, since the 8-14 days from removal from storage to ripe is more than required for distribution and retail sale. Informal tasting of several fruit on opening the CA container suggested flavour would be acceptable after 2-3 days.

'Kensington Pride'

Smartfresh increased the days to eating soft by 2-3 days under CA storage (Table 84). Fruit ripened quicker with longer storage (Table 84). Storage under CA for 5 weeks without SmartFresh resulted in greener fruit compared with 3 and 4 weeks (Table 84).

Skin browning was not obvious after three and four weeks CA storage, but was present with five weeks. SmartFresh had no effect on skin browning. There were no treatment differences for browning under skin (mean rating across all treatments = 0.9), body rots (mean = 0.01), and stem end rots (mean = 0.04).

The percentage of saleable fruit was generally low (Table 84), mainly because of lenticel spotting, abrasion (see below) and browning under skin. Generally SmartFresh increased saleability, while the effect of storage time was inconsistent.

Table 83 External quality of Calypso™ mango following treatment with either nil, low, or high concentrations of SmartFresh, and with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage (firmness of 3).

Weeks of storage (at 12°C)	Storage condition				
	Air			CA	
	SmartFresh			SmartFresh	
	Nil	Low	High	Nil	High
Days from removal to eating soft[1]					
0	14	18	19		
3	10	11	11	10	11
4	10	14	14	6	10
5	10	10	10	8	10
Body rots (0-4)					
0	0 ^{c}	0 ^{c}	0 ^{c}	0 ^{c}	0 ^{c}
3	0 ^{c}	0 ^{c}	0 ^{c}	0 ^{c}	0 ^{c}
4	0 ^{c}	0.07 ^{bc}	0 ^{c}	0 ^{c}	0.06 ^{bc}
5	0.14 ^{ab}	0 ^{c}	0 ^{c}	0 ^{c}	0.19 ^{a}
Lenticel spotting (0-4)					
0	1.6 ^{fgh}	2.4 ^{abcd}	2.4 ^{abcde}		
3	1.9 ^{bcdefg}	3.1 ^{a}	2.6 ^{ab}	0.9 ^{h}	1.9 ^{bcdefg}
4	1.3 ^{gh}	1.3 ^{gh}	1.6 ^{afgh}	2.2 ^{bcdef}	1.8 ^{defg}
5	2.6 ^{abc}	1.9 ^{bcdefg}	2.4 ^{abcd}	1.3 ^{gh}	1.8 ^{cdefg}
Skin browning (0-4)					
0	0.5 ^{cd}	0.5 ^{cd}	0.3 ^{cde}		
3	0 ^{e}	0 ^{e}	0.0 ^{e}	0 ^{e}	0 ^{e}
4	0.6 ^{bc}	0.9 ^{ab}	0.4 ^{cde}	0 ^{e}	0.6 ^{bc}
5	1.2 ^{a}	0.3 ^{cde}	0 ^{e}	0.1 ^{de}	0.1 ^{e}
% saleable fruit[2]					
0	38	50	62		
3	50	37	12	100	50
4	100	71	75	62	75
5	14	75	75	75	50

Means of 8 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

[1] No statistical analysis because the eating soft stage was estimated on average fruit firmness of the whole tray

[2] Calculated as the percentage of fruit with no rots, or other individual defects as less than 3, or a combination of defects with a combined rating of less than 4.

At ripe internal quality

Calypso™

SmartFresh increased the yellow colour of the flesh (lower hue angle) with no storage, and also in most cases following cold storage (Table 85). Storage generally decreased the yellow colour of the flesh compared with no storage, and this effect was particularly obvious after five weeks of storage. The flesh colour of these fruit were visually less yellow than those of non-stored fruit.

Brix was not affected by SmartFresh (Table 85). Controlled atmospheres was usually associated with about 1° higher Brix in the ripe fruit. Controlled atmospheres prevented any reduction in Brix levels during storage, which is likely during air storage. SmartFresh also had no effect on flesh acidity. Without CA, there were indications of reducing acidity with longer storage times. Generally, CA maintained higher acidity levels compared with no CA. The results suggest that CA may result in better flavour compared with no CA because of higher Brix and acidity levels in the ripe fruit.

Table 84 External quality of 'Kensington Pride' mango following treatment with either nil or high concentration of SmartFresh, and 12°C cold storage for 3, 4 or 5 weeks with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality assessed at the eating soft stage (firmness of 3).

Weeks of storage (at 12°C)	SmartFresh	
	Nil	High
Days from removal to eating soft[1]		
3	6	8
4	3	6
5	3	5
Skin colour (1-6)		
3	5.5 [a]	5.5 [a]
4	5.2 [a]	5.2 [a]
5	4.4 [b]	4.9 [ab]
Lenticel spotting (0-4)		
3	1.8	2.2
4	1.9	1.9
5	2.3	2.5
Skin browning (0-4)		
3	0.0 [b]	0.0 [b]
4	0.0 [b]	0.0 [b]
5	0.7 [a]	0.8 [a]
% saleable fruit[2]		
3	21	43
4	7	21
5	29	36

Means of 14 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

[1] No statistical analysis because the eating soft stage was estimated on average fruit firmness of the whole tray

[2] Calculated as the percentage of fruit with no rots, or other individual defects as less than 3, or a combination of defects with a combined rating of less than 4.

'Kensington Pride'

SmartFresh increased the yellow colour of the flesh (lower hue angle) with four and five weeks CA storage (Table 86). CA storage for four and five weeks without SmartFresh decreased the yellow colour of the flesh compared with three weeks CA storage, but this effect was not significant with SmartFresh.

Brix in the ripe fruit was not affected by SmartFresh or CA storage time (Table 86). Flesh acidity was reduced with SmartFresh following three and four weeks CA storage, but there was little effect of storage time on acidity.

Damage before packing

Calypso™

Symptoms of damage caused during harvesting/transport/packing were also monitored (Table 87). Mechanical damage was observed as small cuts and indentations on the fruit, in addition to discrete marks on the skin, possibly due to stem puncture (Plate 34). Abrasion may have occurred during harvesting or transport from Darwin to Katherine for packing. Generally, average severity was low. Mechanical damage symptoms were obvious in non-stored fruit, and were less obvious after storage (perhaps because of masking from other defects). In contrast, abrasion was not obvious in non-stored fruit but became more prominent following storage. Controlled atmospheres appeared

to increase the expression of mechanical damage in the absence of SmartFresh, but there with little consistent effect on abrasion.

Table 85 Internal quality of Calypso™ mango following treatment with either nil, low, or high concentrations of Smartfresh, and with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage. Flesh colour was measured as hue angle, with lower values representing more yellow colour.

Weeks of storage	Storage condition				
	Air			CA	
	SmartFresh			SmartFresh	
	Nil	Low	High	Nil	High
Flesh colour (H°)					
0	91.5 def	88.9 i	88.6 i		
3	90.8 fgh	90.8 fgh	90.8 fg	89.7 hi	90.4 fgh
4	92.0 de	90.9 fg	91.1 efg	92.4 cd	90.4 fgh
5	94.4 ab	94.7 a	93.3 bc	95.1 a	90.7 fgh
Brix (°)					
0					
3	15.3 cde	15.3 cde	15.5 bcd	16.2 ab	16.2 ab
4	14.8 de	14.4 e	14.6 de	15.8 abc	16.3 ab
5	14.5 e	14.9 de	14.8 de	16.5 a	16.0 abc
Acidity (%)					
0					
3	0.13 cde	0.13 cde	0.14 c	0.15 bc	0.15 c
4	0.13 cde	0.10 g	0.10 fg	0.22 a	0.15 c
5	0.11 efg	0.12 ef	0.12 de	0.17 b	0.14 cd

Means of 8 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Table 86 Internal quality of 'Kensington Pride' mango following treatment with either nil or high concentration of SmartFresh, and 12°C cold storage for 3, 4 or 5 weeks with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality assessed at the eating soft stage (firmness of 3). Flesh colour was measured as hue angle, with lower values representing more yellow colour.

Weeks of storage (at 12°C)	SmartFresh	
	Nil	High
Flesh colour (H°)		
3	95.6 c	96.0 bc
4	97.1 ab	95.5 c
5	97.9 a	95.7 bc
Brix (°)		
3	14.9	15.1
4	15.2	15.5
5	16.7	16.0
Acidity (%)		
3	0.90 ab	0.54 b
4	1.13 a	0.65 b
5	1.22 a	0.91 ab

Means of 14 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Across all treatments, the incidence of fruit with any level of severity of physical damage or abrasion was 62% (data not shown). However, out of 144 fruit, only 2 were considered unsaleable due to these defects alone.

Table 87 Skin defects most likely caused by physical damage or abrasion during the harvesting to packing stages on Calypso™ mango following treatment with either nil, low, or high concentrations of Smartfresh, and with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage. .

Weeks of storage	Storage condition				
	Air			CA	
	SmartFresh			SmartFresh	
	Nil	Low	High	Nil	High
Physical damage (0-4)					
0	0.8 bc	0.5 cd	0.5 cd		
3	1.1 ab	1.1 ab	1.4 ab	1.5 a	1.1 ab
4	0.0 d	0.0 d	0.0 d	1.4 ab	0.0 d
5	0.0 d	0.0 d	0.0 d	1.1 ab	0.0 d
Abrasion (0-4)					
0	0.0 d	0.0 d	0.0 d		
3	0.3 cd	0.4 bcd	0.9 a	0.1 d	0.6 abc
4	0.4 bcd	0.2 cd	0.1 d	0.1 d	0.8 ab
5	0.8 ab	0.6 abc	0.2 cd	0.0 d	0.1 d

Means of 8 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

‘Kensington Pride’

Abrasion was relatively common (Table 88; Plate 35), and was one of the factors contributing to reduced saleability. Physical damage included small cuts and indentations on the fruit, and discrete marks on the skin, possibly due to stem puncture (Plate 35). Effects of storage or SmartFresh were nil or inconsistent, as expected.

Shelf life

Calypso™

Shelf life (the days from ripe to end of saleable life) was generally shorter following storage. SmartFresh had little effect on shelf life following air storage, but reduced shelf life with CA storage (Table 89). It is interesting that SmartFresh increased the days from harvest to eating soft by about 4-5 days, but decreased the days from eating soft to unsaleable by the same number of days.

There were no storage or Smartfresh effects on body rots (mean rating across all treatments of 0.02) or stem end rots (mean rating of 0.15). Five weeks storage (both air and CA) increased the severity of denditric spot (mean rating of 0.5-0.7 for Air, and 0.2-0.5 for CA, with severity increasing with longer storage).

Lenticel spotting was the main factor terminating shelf life (Table 89; Plate 39). CA storage without Smartfresh resulted in less lenticel spotting compared with no storage, but there was little other consistent effect of storage atmosphere or Smartfresh on lenticel spotting severity at the end of shelf life. SmartFresh reduced skin browning when there was no storage, but had little effect with either air or CA storage. Generally, air storage reduced the severity of skin browning compared with no storage, a similar effect observed for CA storage for 5 weeks compared to CA for 3 and 4 weeks.

Table 88 Skin defects most likely caused by physical damage or abrasion during the harvesting to packing stages on 'Kensington Pride' mango following treatment with either nil or high concentration of SmartFresh, and 12°C cold storage for 3, 4 or 5 weeks with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality assessed at the eating soft stage (firmness of 3).

Weeks of storage (at 12°C)	SmartFresh	
	Nil	High
Physical damage (0-4)		
3	1.4 [a]	0.8 [b]
4	0.6 [b]	0.9 [b]
5	0.0 [c]	0.0 [c]
Abrasion (0-4)		
3	1.5 [b]	1.4 [b]
4	2.7 [a]	1.6 [b]
5	1.1 [b]	1.1 [b]

Means of 14 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Table 89 External quality of Calypso™ mango following treatment with either no, or low, or high concentrations of SmartFresh, and with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality assessed at the end of saleable life.

Weeks of storage (at 12°C)	Storage condition				
	Air			CA	
	SmartFresh			SmartFresh	
	Nil	Low	High	Nil	High
Days from ripe to end of saleable life[1,2]					
0	10	6	5		
3	4	3	3	4	3
4	4	3	3	8	4
5	4	4	3	6	4
Hand firmness (0-4)					
0	3.9 [a]	3.8 [a]	3.8 [a]		
3	3.1 [cdef]	3.1 [cdef]	3.3 [b]	3.1 [cdef]	2.9 [cdef]
4	3.0 [cdef]	2.8 [f]	2.9 [def]	3.0 [cdef]	3.0 [cdef]
5	3.1 [cd]	2.8 [ef]	3.1 [cde]	3.1 [bc]	2.9 [def]
Lenticel spotting (0-4)					
0	3.3 [a]	3.1 [a]	3.3 [a]		
3	2.7 [ab]	2.1 [bc]	2.0 [bc]	2.1 [bc]	2.5 [abc]
4	2.5 [abc]	1.6 [c]	2.1 [bc]	2.1 [bc]	2.4 [abc]
5	2.6 [ab]	2.3 [abc]	2.4 [abc]	1.9 [bc]	2.8 [ab]
Skin browning (0-4)					
0	2.3 [a]	1.6 [bc]	1.3 [bc]		
3	1.6 [bc]	1.3 [bc]	1.5 [bc]	1.0 [cd]	1.9 [ab]
4	0.9 [cde]	0.3 [ef]	0.4 [def]	1.3 [bc]	1.0 [cd]
5	0.6 [def]	0.3 [ef]	0.5 [def]	0.2 [f]	0.4 [def]

Means of 8 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

[1] No statistical analysis because the eating soft stage was estimated on average fruit firmness of the whole tray

[2] End of saleable life was considered when fruit was rotten, or with an individual defect severity of 3 or higher, or when the combination of defects had a combined rating of more than 4.

'Kensington Pride'

For most treatments, the fruit had reached the end of saleable life before they were ripe, mainly because of high levels of lenticel spotting, skin browning and abrasion (Table 90).

Compared with control fruit, the severity of stem end rots was higher for SmartFresh treated fruit after three and four weeks, but not after 5 weeks (Table 90). There was no treatment effect for body rots severity (overall mean rating was 0.1).

There was no treatment effect on skin colour at the end of shelf life (mean rating across all treatments was 5.1).

Table 90 External quality of 'Kensington Pride' mango following treatment with either nil or high concentration of SmartFresh, and 12°C cold storage for 3, 4 or 5 weeks with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality assessed at the end of saleable life.

Weeks of storage (at 12°C)	SmartFresh	
	Nil	High
Days from ripe to end of saleable life[1]		
3	0	6
4	0	1
5	3	1
Hand firmness (0-4)		
3	3.0 bc	3.9 a
4	3.9 a	3.8 a
5	3.3 b	3.0 c
Lenticel spotting (0-4)		
3	2.2 c	3.4 a
4	3.0 ab	3.2 ab
5	2.8 b	2.7 b
Skin browning (0-4)		
3	0.0 c	1.1 a
4	0.9 a	1.1 a
5	0.7 ab	0.4 bc
Abrasion (0-4)		
3	2.3 a	0.9 bc
4	1.4 b	1.2 b
5	0.7 c	0.5 c
Stem end rots (0-4)		
3	0.0 b	0.5 a
4	0.0 b	0.4 a
5	0.0 b	0.0 b

Means of 14 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

[1] No statistical analysis because days were estimated on average fruit firmness of the whole tray

7.3.1.3.4. Katherine

On removal external quality

Fruit from CA were softer on removal compared with no CA (Table 91). SmartFresh had no significant effect on firmness. Firmness decreased with longer storage times. Fruit from CA also had more green skin colour (Plate 40), and there was no effect of storage duration. Storage treatment had an inconsistent effect on lenticel spotting severity. Controlled atmospheres did not affect skin browning, while severity increased with longer storage times. And skin browning severity increased slightly with CA.

Table 91 Katherine: External quality of Calypso™ mango on removal from 12°C cold storage for 3, 4 or 5 weeks either without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide).

	Storage condition		Storage time (weeks)		
	Air	CA	3	4	5
Acoustic firmness (Aweta)	32.5 [a]	21.9 [b]	32.3 [a]	22.8 [b]	26.5 [b]
Skin colour (1-6)	5.9 [a]	4.5 [b]			
Skin browning (0-4)			0.2 [b]	0.6 [a]	0.5 [a]
Under the skin browning (0-4)	0.2 [b]	0.6 [a]			

Means of 34 fruit per treatment.

For each quality attribute, means for either storage condition and storage time with different letters are significantly different ($P<0.5$) as tested by LSD.

At ripe external appearance

The long time for the non-stored fruit to reach eating soft (26 days) was because they remained unusually firm. Storage again reduced the time to ripen compared with no storage, but CA had little effect on ripening (Table 92). All fruit had reached full yellow skin colour by eating soft (data not presented). Lenticel spotting severity averaged 1.7, being the main cause of loss of saleability, but with no treatment effect on severity (Plate 40).

Disease severity was low across all treatments (Table 92). Body rots, stem end rots and dendritic spot was absent in ripe fruit from four weeks storage, but increased with five weeks. Skin browning severity was highest with no storage, but there was no effect of storage time or CA on severity. Under skin browning (Plate 34) increased with storage time and with CA treatment.

There were usually less saleable fruit with increasing storage time. Controlled atmospheres had inconsistent results, with increased percentage of saleable fruit with four weeks storage, but small reductions after three and five weeks.

At ripe internal quality

There was slightly less flesh yellow colour (higher hue angle) in the ripe flesh following storage compared with no storage, but there was no effect of CA on flesh colour (Table 93). Storage duration had no effect on Brix. However, CA increased flesh Brix compared with no CA. Acidity was higher after storage, with CA resulting in higher acidity compared with no CA.

Damage before packing

Average severity of mechanical damage was 0.3, and there was no effect of storage treatment on damage. No skin abrasion was observed.

End of shelf life

Shelf life was generally reduced with storage for up to four weeks (Table 94). Controlled atmosphere had no effect on shelf life (Table 94).

Controlled atmosphere had no effect on lenticel spotting severity after three and four weeks storage, but after five weeks severity was higher with CA compared with no CA (Table 94).

Severity of body rots was low and with little consistent effect of storage time or CA (Table 94). There was no effect of CA or storage time on stem end rots (mean rating averaged across all treatments of 0.1).

Table 92 Katherine: External quality of Calypso™ mango with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage (firmness of 3).

Weeks of storage	Storage condition	
	Air	CA
Days from removal to ripe[1]		
0	17	
3	8	8
4	7	6
5	10	9
Body rots (0-4)		
0	0 c	
3	0 c	0 c
4	0.2 a	0 c
5	0 bc	0.1 b
Stem end rots (0-4)		
0	0 b	
3	0 b	0 b
4	0 b	0 b
5	0.2 a	0 b
Dendritic spot (0-4)		
0	0 c	
3	0 c	0 c
4	0 c	0 c
5	0.8 a	0.3 b
Skin browning (0-4)		
0	1.4 a	
3	0.4 b	0.5 b
4	0.7 b	0.7 b
5	0.6 b	0.6 b
Under skin browning (0-4)		
0	0 c	
3	0 c	0.7 ab
4	0.5 bc	0.4 bc
5	0.4 bc	1.1 a
% of saleable fruit[2]		
0	72	
3	75	67
4	33	82
5	59	40

Means of 18 fruit per treatment.

[1] No statistical analysis because the eating soft stage was estimated on average fruit firmness of the whole tray

[2] Calculated as the percentage of fruit with no rots, or other individual defects as less than 3, or a combination of defects with a combined rating of less than 4.

Under skin browning was not consistently affected by storage time, however severity was often greater with CA. There was no effect of storage condition or time on skin browning (mean = 0.8).

The major defects contributing to the end of shelf life were lenticel spotting and skin browning. Disease severity was relatively low.

Table 93 Katherine: Internal quality of Calypso™ mango with either no cold storage, or 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage (firmness of 3).

Weeks of storage	Storage condition	
	Air	CA
Flesh colour (H°)		
0	89.5 [c]	
3	90.3 [abc]	90.0 [bc]
4	91.0 [a]	91.1 [a]
5	90.5 [ab]	90.7 [ab]
Brix (°)		
0	17.6 [bc]	
3	17.5 [bc]	18.7 [ab]
4	17.5 [bc]	18.1 [b]
5	16.5 [c]	19.5 [a]
Acidity (%)		
0	0.16 [c]	
3	0.23 [b]	0.28 [a]
4	0.23 [b]	0.31 [a]
5	0.18 [c]	0.23 [b]

Means of 18 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

7.3.1.3.5. Dimbulah

At removal external appearance

Fruit were generally softer on removal with increasing storage duration (Table 95). Controlled atmospheres resulted in softer fruit on removal. Controlled atmospheres significantly retained more green colour on the skin (average of 5.4) compared with no CA (5.8). Also, longer storage durations resulted in less green colour (increasing from 5.3 after three weeks storage to 5.7-5.9 with 4-5 weeks storage).

At removal from storage there was no consistent effect of storage duration on lenticel spotting or skin browning severity severity, however CA generally increased the severity of these defects.

At ripe external appearance

The long time for the non-stored fruit to reach eating soft (26 days) was because they remained unusually firm (Table 96). Because of the delay in assessing quality of these fruit, lenticel spotting and skin browning severity was very high. The stored fruit reached eating soft within the expected time, and lenticel spotting was significantly lower. There was no effect of CA or storage time on days to eating soft or lenticel spotting.

As with fruit from the Northern Territory, skin browning was lower with short term storage, but increased with five weeks storage. This was observed without and with CA. Body rots severity (average of 0.02 across all treatments) and stem end rots severity (average of 0.08) were very low (Plate 42) with no treatment effects (data not presented). No dendritic spot was observed.

There were more saleable fruit with storage compared with no storage, again because of the higher lenticel spotting and skin browning severity in the non-stored fruit. There were also more saleable fruit at four weeks storage because of less skin browning. There were indications of more saleable fruit at five weeks with CA compared with no CA, but there was no CA effect with shorter durations.

Table 94 Katherine: Shelf life, and external quality at the end of shelf life, of Calypso™ mango following 12°C cold storage for 3, 4 or 5 weeks with or without controlled atmospheres.

	Storage condition	
Weeks of storage	No CA	With CA
Shelf life (days)[1]		
0	24	
3	18	18
4	12	12
5	22	22
Firmness (hand)		
0	3.8 [a]	
3	3.2 [bc]	3.3 [b]
4	3.2 [bc]	3.3 [b]
5	3.2 [bc]	3.0 [c]
Firmness (Aweta)		
0	13.3 [bc]	
3	15.3 [a]	12.6 [c]
4	15.0 [ab]	12.4 [c]
5	13.7 [abc]	13.7 [abc]
Lenticel spotting (0-4)		
0	2.8 [a]	
3	1.5 [c]	1.3 [cd]
4	1.2 [cd]	0.8 [d]
5	1.5 [c]	2.1 [b]
Under skin browning (0-4)		
0	0.0 [b]	
3	0.3 [ab]	0.9 [a]
4	0.2 [b]	0.9 [a]
5	0.0 [b]	0.2 [b]
Body rots (0-4)		
0	0.0 [b]	
3	0.6 [a]	0.3 [ab]
4	0.0 [b]	0.0 [b]
5	0.1 [b]	0.2 [b]

Means of 18 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

[1] Data was on average for the whole trays or no statistical analysis was possible

Internal quality

The flesh colour was generally more yellow than observed with Northern Territory fruit (Table 97). Ripe flesh yellow colour decreased (increase H°) with storage. There was little consistent effect of CA on flesh colour.

There were no treatment effects on Brix, which averaged 15.5 across all treatments. Acidity was higher with increased storage duration, and also with CA (Table 97).

Table 95 Dimbulah: External quality of Calypso™ mango on removal from 12°C cold storage for 3, 4 or 5 weeks without (air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide).

Weeks of storage	Storage condition	
	Air	CA
Hand firmness (0-4)		
3	0.2 [e]	0.8 [d]
4	1.4 [b]	1.2 [bc]
5	1.1 [c]	2.2 [a]
Skin colour (1-6)		
3		
4		
5		
Lenticel spotting (0-4)		
3	0.3 [cd]	0.5 [bc]
4	0.1 [e]	0.9 [a]
5	0.3 [de]	0.6 [b]
Skin browning (0-4)		
3	0.1 [bc]	0.1 [bc]
4	0.1 [c]	0.9 [a]
5	0.2 [b]	0.2 [bc]

Means of 24 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Table 96 External quality of Dimbulah Calypso™ mango following 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage (firmness of 3).

Weeks of storage	Storage condition	
	Air	CA
Days from removal to ripe		
0	26	
3	12	12
4	10	10
5	10	10
Firmness (hand)		
0	3.0 [a]	
3	2.7 [c]	2.8 [bc]
4	2.9 [ab]	3.0 [a]
5	2.8 [bc]	3.0 [a]
Lenticel spotting (0-4)		
0	3.5 [a]	
3	1.2 [cd]	1.8 [b]
4	0.5 [e]	0.3 [e]
5	1.4 [bc]	1.0 [d]
Skin browning (0-4)		
0	2.9 [a]	
3	1.6 [b]	1.7 [b]
4	0.3 [d]	0.3 [d]
5	1.5 [bc]	1.0 [c]
% saleable fruit		
0	4	
3	58	54
4	97	87
5	58	79

Means of 24 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Table 97 Dimbulah: Internal quality of Calypso™ mango following 12°C cold storage for 3, 4 or 5 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the eating soft stage. Higher hue angle (Ho) indicates more yellow colour.

Weeks of storage	Storage condition	
	Air	CA
Flesh colour (H^o)		
0	85.9 [e]	
3	89.2 [c]	87.9 [d]
4	90.8 [b]	90.9 [b]
5	91.5 [b]	92.6 [a]
Acidity (%)		
0	0.12 [e]	
3	0.13 [de]	0.14 [cd]
4	0.15 [bc]	0.16 [b]
5	0.15 [cd]	0.20 [a]

Means of 24 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Damage before packing

Mechanical damage was relatively minor and there was no consistent effect of storage on damage expression (Table 98). Abrasion was also minor, but became slightly more obvious at five weeks storage.

Table 98 Skin damage on Dimbulah Calypso™ mango following 12°C cold storage for 3, 4 or 5 weeks with or without controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Damage was most likely caused during the harvesting to packing stages.

Weeks of storage	Storage condition	
	No CA	With CA
Mechanical damage (0-4)		
0	0.1 [bc]	
3	0.6 [a]	0.3 [b]
4	0.1 [bc]	0.0 [c]
5	0.6 [a]	0.3 [b]
Abrasion (0-4)		
0	0.1 [b]	
3	0.0 [b]	0.0 [b]
4	0.0 [b]	0.0 [b]
5	0.2 [ab]	0.4 [a]

Means of 24 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

End of shelf life

Generally, shelf life decreased with increasing storage time, but there was little effect of CA on shelf life (Table 99).

Fruit were generally still quite firm at the end of shelf life for most treatments (mean across all treatments was 3.2).

Lenticel spotting and skin browning were the major factors contributing to the end of shelf life, but there was no consistent effect of storage duration or CA on those defects (Table 99). Under skin browning was more severe with four weeks storage, and was lower with CA at this duration.

Body rots severity (average of 0.1 across all treatments) and stem end rots severity (average of 0.3) were very low, with no treatment effects (data not presented).

Table 99 Dimbulah: Shelf life and external quality of Calypso™ mango following 12°C cold storage for 3, 4 or 5 weeks without (air) or with controlled atmospheres (CA; 3% oxygen, less than 0.5% carbon dioxide). Fruit quality was assessed at the end of shelf life.

Weeks of storage	Storage condition	
	Air	CA
Shelf life (days)		
0	28	
3	19	19
4	17	17
5	12	10
Firmness (hand)		
0	3.2 [bc]	
3	3.0 [cd]	3.0 [d]
4	3.3 [ab]	3.2 [ab]
5	2.9 [d]	3.4 [a]
Lenticel spotting (0-4)		
0	3.4 [a]	
3	2.0 [bc]	2.2 [b]
4	2.0 [bc]	2.2 [b]
5	1.6 [cd]	1.2 [d]
Skin browning (0-4)		
0	2.6 [a]	
3	1.9 [bc]	2.3 [ab]
4	1.9 [bc]	2.0 [abc]
5	1.6 [cd]	1.2 [d]
Under skin browning		
0	0.0 [b]	
3	0.0 [b]	0.1 [b]
4	0.5 [a]	0.1 [b]
5	0.2 [b]	0.0 [b]

Means of 24 fruit per treatment.

For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD

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0 ppb

625 ppb

1000 ppb

Plate 27 Calypso™ fruit one day after removal from the container, and held at 20°C with ethylene for 12 hrs.

1000 ppb	625 ppb	0 ppb

Plate 28 Calypso™ fruit six days after removal from the container (12 hrs at 20°C with ethylene, then held at room temperature. Fruit were treated with 1000, 635 or 0 ppb SmartFresh. Diseased fruit were removed from the trays.

Plate 29 Calypso™ fruit nine days after removal from the container and held at room temperature. Fruit were treated with 1000, 635 or 0 ppb SmartFresh. Diseased fruit were removed from the trays.

21st December; four days after removal	
	
26th December; nine days after removal	
	
26th December, peeled fruit	
	
Calypso™, SmartFresh at 650 ppb	Calypso™, no SmartFresh

Plate 30 Calypso™ fruit four and nine days after removal from the container, held at 20°C with ethylene for 12 hours then at room temperature. Diseased fruit were removed from the trays.

Plate 31 ‘Kensington Pride’ mango fruit one day after removal from the container, and held for 12 hrs at 20°C with ethylene. Top row treated with 1000 ppb SmartFresh, and the bottom row not treated with SmartFresh.

Plate 32 ‘Kensington Pride’ fruit six days after removal from the container, held at 20°C with ethylene for 12 hrs, then at room temperature. Fruit were treated with 1000 or 0 ppb SmartFresh.

0 ppb SmartFresh three days after removal. Note the light and dark-coloured stem end rot symptoms.

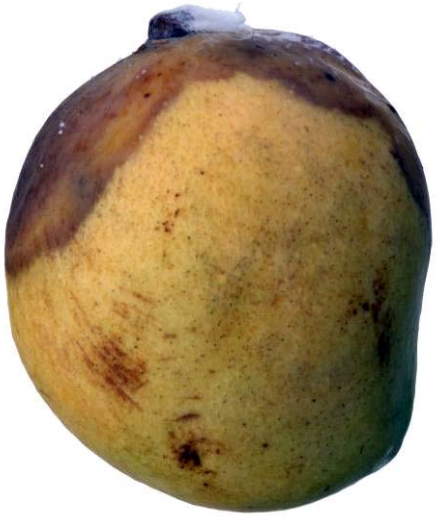
1000 ppb SmartFresh five days after removal

Plate 33 'Kensington Pride' mango fruit after seafreight held at 20°C with ethylene for 12 hrs, then at room temperature. Note the dark and light coloured forms of stem end rot.

Firm light stem end rot

Firm dark stem end rot

Firm dark stem end rot

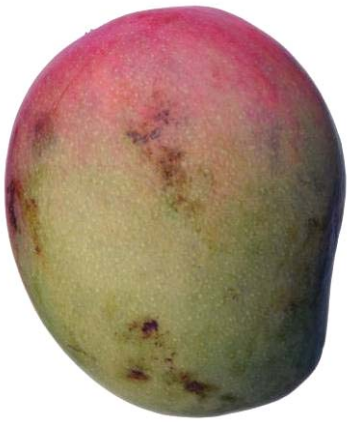


Soft dark stem end rot

Discrete browning most likely due to mechanical means

Plate 34 Quality issues noted on Calypso^{TM} mango one day after removal from the container.

Under skin browning



More blotchy skin browning

Plate 34 cont. Quality issues noted on Calypso™ mango one day after removal from the container.

Abrasion

Discrete browning

Under skin browning

Plate 35 Quality issues noted on ripe ‘Kensington Pride’ mango following CA storage.

	No CA	CA
SmartFresh: Nil		
Low		
High		

Plate 36 Darwin, static trial at eating soft : Calypso^{TM} mango fruit after storage for three weeks under several controlled atmosphere and SmartFresh regimes

SmartFresh:	No CA	CA
Nil		
Low		
High		

Plate 37 Darwin, static trial, at eating soft: Calypso^{TM} mango fruit, after four weeks storage under several controlled atmosphere and SmartFresh regimes

	No CA	CA
SmartFresh: Nil		
Low		
High		

Plate 38 Darwin, static trial, at eating soft: Calypso^{TM} mango fruit after five weeks storage under several controlled atmosphere and SmartFresh regimes

	No CA	CA
SmartFresh: Nil		
Low		
High		

Plate 39 Darwin, static trial, at the end of shelf life: IIlustrates that lenticel spotting, skin browning and rots were the main factors contributing to end of shelf life. Empty sections of the tray are where diseased fruit have been removed.

	No CA	CA
Storage for 3 weeks		
4 weeks		
5 weeks		

Plate 40 Katherine, at removal from cold and controlled atmosphere storage for 3-5 weeks.

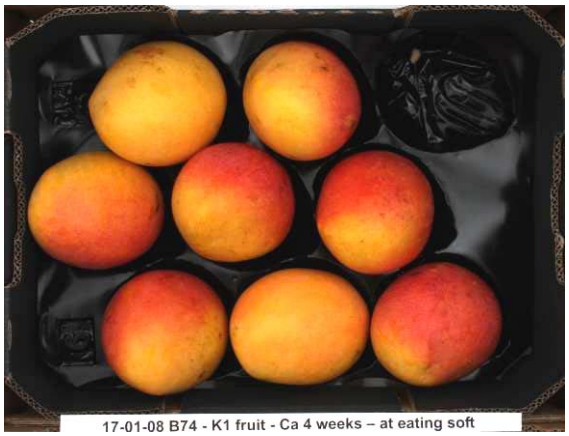
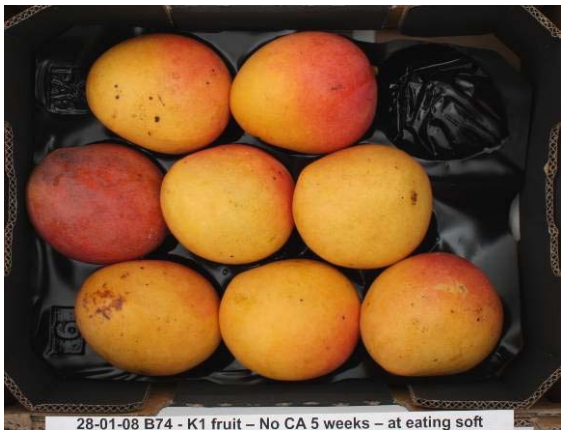
	No CA	CA
3 weeks		
4 weeks		
5 weeks		

Plate 41 Katherine, at eating soft: following storage with and without controlled atmospheres for 3-5 weeks

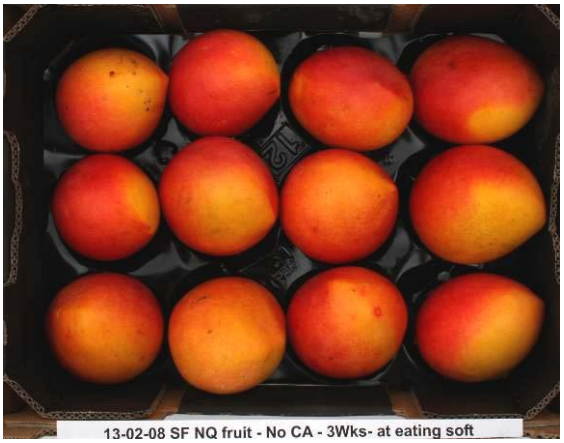
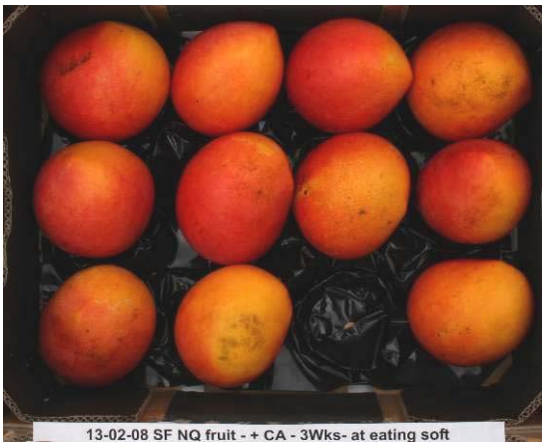
	No CA	CA
3 weeks		
4 weeks		
5 weeks		

Plate 42 Dimbulah, at eating soft: following storage with and without controlled atmospheres for 3-5 weeks.

7.3.1.4. Conclusions and recommendations

- Upon removal from the CA container, fruit were fairly soft and coloured. Smartfresh had little impact on either firmness or skin colour at removal.
- With the seafreight trial, about 70-100% of the fruit were saleable 2-3 days after removal, but this percentage decreased rapidly with time, and less than 20% of the fruit were saleable 8 days after removal.
- With the static trial, the most obvious effects of CA were in retaining skin green colour on removal and increasing softness compared to air storage. The increased softness with CA has been observed in other trials, and does not reflect excessive ripening.
- Total time from removal from storage to the end of saleable life was about 10-18 days for Calypso™, and 3-8 days for 'Kensington Pride'.
- Smartfresh increased the days from removal to eating soft for Calypso™, but reduced its shelf life. Smartfresh slightly increased the days to eating soft in 'Kensington Pride', but by that stage the fruit were unsaleable mainly because of abrasion, lenticel spotting and skin browning
- Smartfresh may maintain 'Kensington Pride' saleable fruit quality for 1-3 days longer compared with no SmartFresh, but this needs to be confirmed. There was less obvious effect with Calypso™.
- There were only small benefits to shelf life and quality with laboratory CA storage. However, these fruit were held only under O_2 control with no CO_2, and the coldroom was opened at least weekly to remove samples.
- Cold storage generally shortened the days to ripen in Calypso™ fruit from both Katherine and Dimbulah.
- Rots severity was low even on the ripe fruit. There was very little body rots, and only the occasional fruit was severely affected by stem end rot.
- Lenticel spotting and skin browning were the major factors determining the end of shelf life. Lenticel spotting generally increased with longer storage times in Calypso™ fruit from Darwin, but there were no effect in fruit from Katherine or Dimbulah. Controlled atmospheres reduced lenticel spotting in some cases in Calypso™ fruit from Darwin, but not from the other two locations.
- Smartfresh increased lenticel spotting on the ripe Calypso™ fruit, possibly because of the longer time to ripen. It had no effect on 'Kensington Pride' lenticel spotting. There were also indications that under skin browning increased with SmartFresh.
- Smartfresh can increase the yellow colour of the ripe fruit flesh in both Calypso™ and 'Kensington Pride'. Flesh was less yellow after storage in Calypso™ fruit from both Katherine and Dimbulah compared with no storage. CA had no effect on flesh colour.
- Controlled atmospheres increased flesh Brix in Calypso™ fruit from both Darwin and Katherine (but not Dimbulah), and increased flesh acidity in ripe Calypso™ in fruit from all locations. This may suggest that CA may improve flavour.

Therefore:

- The fruit from both the Northern Territory and north Queensland were relatively disease-free. The major disease was stem end rot. Hot water fungicide treatments should be considered provided it does not breach residues requirements.
- Despite the small effects of CA in the static trials, we recommend that this be used for all sea shipments to the EU because of risks of quality loss. The present results do not support

- The risk of disease, and physical damage during harvest and packing needs to be minimised.

7.3.2. Can high CO_2 retard green colour loss during CA?

7.3.2.1. Introduction

Overseas markets often prefer mangoes to arrive in a backward state (with less than 50% yellow colour on the skin) to give the impression of freshness and have enough time to distribute to retailers.

The rapid development of yellow colour on Calypso™ fruit after harvest is advantageous for domestic marketing, but may work against the requirements of overseas importers. Past experience indicates that refrigeration alone does not sufficiently retard green colour. Work within the Global Markets Initiative (GMI) mango exports project also indicated that refrigeration with reduced oxygen did not sufficiently retard green colour loss.

Using high carbon dioxide in combination with low oxygen and temperature can help retard green colour loss in other fruit. This report describes the effect of high carbon dioxide concentrations, in combination with low oxygen concentrations, on skin colour after 1-3 weeks cold storage to simulate seafreight exports to Asia. In addition, we tested whether SmartFresh could provide the same response. The aim was to ensure that the fruit had at least 50% green colour on outturn.

7.3.2.2. Materials and methods

7.3.2.2.1. Fruit samples and treatments

Commercial Calypso™ mango fruit were collected from three separate blocks (replications) on two farms in the Bundaberg area on January 22nd 2009. Fifteen trays per block (about 16 fruit per tray) were sampled at the end of the packing line following normal commercial practice. Fruit were transported to the Maroochy Research Station (MRS) laboratory at Nambour within 24 hours from picking. On arrival at the laboratory the percent dry matter (DM) was determined on 10 fruit per replication by cutting longitudinal peeled sections from each cheek, dicing and drying at 65ºC until constant weight (about 3 days). The DM was expressed as percentage of dry tissue in relation to fresh tissue. The DM ranged from 14.8 to 16.3% for the three replications.

The treatments outlined in Table 100 were applied. In summary these were:

- Not cold stored (ripened at 20ºC with no cold storage)
- Treated with SmartFresh at either 0.6 or 1.0 ppm then either cold stored or ripened immediately
- Cold stored under air (with no adjustment of the oxygen or carbon dioxide) for 1-3 weeks before ripening
- Cold stored under controlled atmospheres at 3% oxygen and 5% carbon dioxide for 1-3 weeks before ripening.

Within 4hr of arrival at the laboratory all fruit for the cold storage treatments (SM, Air and CA) were held at 12ºC for about 4hr before treatment application. For the SmartFresh treatments, the fruit were placed into $1m^3$ gassing tents made of high density polyethylene plastic (100 μm) sealed with duct tape and held for 24 hr at 12°C. Inside the tents 0.625 or 1.0 ppm 1-methylcyclopropene (1-MCP) was produced by adding tablets of the commercial formulation SmartFresh℠ (supplied by AgroFresh, USA) to 18 ml of activator solution provided by the supplier. A small fan, and activated lime was placed in each tent to promote circulation and reduce carbon dioxide

accumulation. Subsequent use of the SmartFresh tablets from the same batch on custard apples indicated high activity of the product.

Upon removal from the tents, fruit were transferred to a coldroom at 12ºC together with the fruit from the air treatments (held at 12ºC). For the CA treatments, fruit were held overnight at 12ºC before being placed in the CA coldroom. At the start of CA storage and after every removal, the set gas composition in the room was achieved in about 2-3 hours.

The control treatment (non-stored) fruit were placed at 20°C immediately on arrival at laboratory. Every week one tray per treatment per block was removed from cold storage and assessed for firmness and skin colour at removal (see below).

Fruit were ripened at 20°C, and none of the fruit were treated with ethylene gas (often used the trigger ripening).

Table 100 Treatments applied to Calypso™ mango fruit to simulate controlled atmosphere (CA) seafreight to Asian markets. Fruit were held at 12oC in all SmartFresh (SM) and storage treatments.

Treatment	Procedure before ripening at 20°C
Control	None (no storage)
SM 0.6 C	SmartFresh 0.6 ppm for 20 hours (no storage)
SM 1.0 C	SmartFresh 1.0 ppm for 20 hours (no storage)
SM 0.6-1wk	SmartFresh 0.6 ppm for 20 hours, then air storage for 1 week
SM 0.6-2wk	SmartFresh 0.6 ppm for 20 hours, then air storage for 2 weeks
SM 0.6-3wk	SmartFresh 0.6 ppm for 20 hours, then air storage for 3 weeks
SM 1.0-1wk	SmartFresh 1.0 ppm for 20 hours, then air storage for 1 week
SM 1.0-2wk	SmartFresh 1.0 ppm for 20 hours, then air storage for 2 weeks
SM 1.0-3wk	SmartFresh 1.0 ppm for 20 hours, then air storage for 3 weeks
Air 1wk	Air storage for 1 week
Air 2wk	Air storage for 2 weeks
Air 3wk	Air storage for 3 weeks
CA 1wk	CA (3% O_2, 5%CO_2) storage for 1 week
CA 2wk	CA (3% O_2, 5%CO_2) storage for 2 weeks
CA 3wk	CA (3% O_2, 5%CO_2) storage for 3 weeks

7.3.2.2.2. Controlling the oxygen and carbon dioxide

The oxygen concentration in a 3mx2mx2m cold room was kept at about 3% by a constant injection of about 98% nitrogen into the room from a permeable membrane gas filtration unit (Permea). Oxygen concentrations were constantly monitored by a Servamex oxygen meter connected to a computer. When the generator nitrogen was insufficient to maintain 3% oxygen, a dedicated monitoring program activated a solenoid attached to a bank of nitrogen cylinders for about two minutes in every 20 minutes until the oxygen concentration reached the 3% setpoint. At the start of the trial, and following removal of fruit after one and two weeks, bottle nitrogen was injected into the room continually for about 60 minutes to rapidly bring the oxygen concentration to about 5%. Thereafter, bottle nitrogen injection was controlled by computer to bring down the oxygen to 3%.

Carbon dioxide concentrations were kept at approx. 5% by monitored carbon dioxide concentrations with a PP Systems WMA-4 CO2 analyser, and injecting bottled carbon dioxide as required by a separate control box and solenoid.

The oxygen and carbon dioxide concentrations from the oxygen and carbon dioxide analysers (recorded every 30 minutes), and activation of the nitrogen solenoid was via a LJ Tick-Relay Driver (LabJack).

7.3.2.2.3. Quality assessment

The days to ripe was determined for each tray based on time from harvest (for non-stored fruit) or time from removal (for stored fruit) to reach full yellow colour. From three days after removal, external appearance was assessed every 2-3 days for 10 days after each fruit reached full colour, or until most fruit in the tray lost saleability.

Fruit firmness was assessed using a hand firmness scale (Table 78) and the Aweta Acoustic Firmness Tester to provide an objective measure of firmness. The Aweta unit is a non-destructive system based on the analysis of the resonance frequencies produced when the fruit surface is tapped. Its scale decreases as the fruit soften.

The background skin colour was rated using the following scale: 1 = 0-10% yellow; 2 = 10-30% yellow; 3 = 30-50% yellow; 4 = 50-70% yellow; 5 = 70-90% yellow, and 6 = 90-100% yellow).

External defects were rated as described in Table 78.

Table 101 Rating scales used in quality assessment of Calypso^{TM} mango fruit.

Rating	Firmness	Lenticel spotting	Skin browning and rots
0	Hard	Nil	Nil
1	Rubbery	To 10%	To 3cm^2
2	Sprung	To 25%	To 6 cm^2
3	Soft	To 50%	To 25%
4	Very soft	> 50%	> 25%

3cm^2 is the size of a 5 cent piece
6cm^2 is the size of a 20 cent piece

Fruit were considered to be saleable if there were no rots, or other individual defects were less than severity 3, or all combination of defects had a combined rating of 4 or less.

To determine if the treatments affected flavour at ripe, one cheek from each fruit was removed, the flesh diced and combined with another five fruit in the same replication and treatment, to provide one composite sample per treatment and replication. The composite samples were presented to six trained staff from the postharvest unit at MRS for flavour assessment. A 1-9 rating scale (1=dislike extremely; 9=like extremely). Flavour was assessed only for the two weeks storage duration.

7.3.2.3. Results

The oxygen and carbon dioxide concentrations in the coldroom were maintained within specified limits except when the rooms were opened for fruit sampling and when carbon dioxide supplies ran out (Figure 49).

7.3.2.3.1. External quality at removal from 12ºC storage

At removal from one week cold storage, CA stored fruit had lower skin colour scores (less yellow colour; retained more green colour) than air-stored fruit (Table 102; Plate 43). After 2-3 weeks cold storage, the CA fruit had less yellow that all other cold stored fruit. In contrast, there was little effect of SmartFresh on skin colour at removal for any storage time. With CA, there was more than 50% green colour on the fruit at all removals.

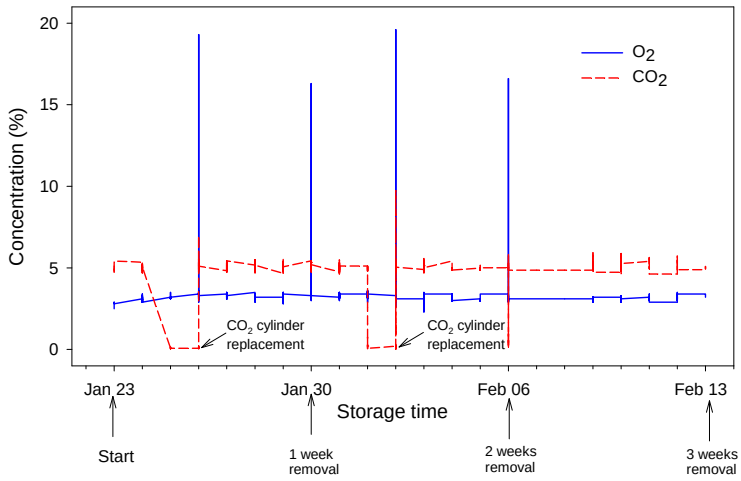


Figure 49 The concentrations (%) of oxygen (O2) and carbon dioxide (CO2) during controlled atmosphere (CA) storage of Calypso™ mango fruit at 12ºC for one, two and three weeks.

Table 102 At removal from storage: External quality of Calypso™ mango following treatment with either nil, 0.6 ppm, or 1.0 ppm of SmartFresh, and with either no storage, or storage at 12°C for one, two or three weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide). The "No storage" fruit were assessed on arrival at the laboratory.

Treatment	Colour (1-6)	Hand firmness (0-4)	Aweta firmness
No cold storage			
Control	2.7 cd	0.2 d	-
SmartFresh 0.6	2.3 de	0.2 def	-
SmartFresh 1.0	2.4 de	0.2 d	-
1 week cold storage			
Air	2.4 de	0.0 fg	69 a
SmartFresh 0.6	2.2 ef	0.1 efg	68 a
SmartFresh 1.0	2.0 efg	0.0 g	67 a
CA	1.9 fg	0.2 de	58 bc
2 weeks cold storage			
Air	3.0 c	0.1 defg	61 b
SmartFresh 0.6	3.1 bc	0.1 efg	60 b
SmartFresh 1.0	2.9 c	0.0 fg	56 c
CA	2.1 efg	0.6 b	38 f
3 weeks cold storage			
Air	3.5 a	0.4 c	46 e
SmartFresh 0.6	3.5 ab	0.2 d	51 d
SmartFresh 1.0	3.5 a	0.4 c	49 de
CA	1.7 g	1.0 a	19 g
LSD	*0.5*	*0.1*	*3.3*

Means of 48 fruit per treatment.
Means in columns with different letters are significantly different (P<0.05) as tested by LSD

There was little loss in firmness at removal from one week storage compared with no storage, and there were no treatment differences (Table 102). At two weeks storage, CA-treated fruit were softer at removal compared with the other treatments. By three weeks, all treatments had softened slightly, but CA-treated fruit had softened the most. There was no consistent effect of SmartFresh on firmness at removal, compared with control. Hand firmness and Aweta indicated similar firmness responses.

The reduced firmness with CA has frequently been observed on other Australian CA trials with mangoes, and is not thought to be a significant customer concern.

With no storage, the increase in yellow colour during ripening was slower with 1 ppm SmartFresh over the first five days, but the differences were small (Figure 50). Following one week storage, there were only minor treatment differences in colour development. From two weeks of storage onwards CA-treated fruit had significantly less yellow colour on removal, and for about five days during ripening. This difference was greater with longer storage. There was no effect of SmartFresh on skin colour, compared with all other treatments.

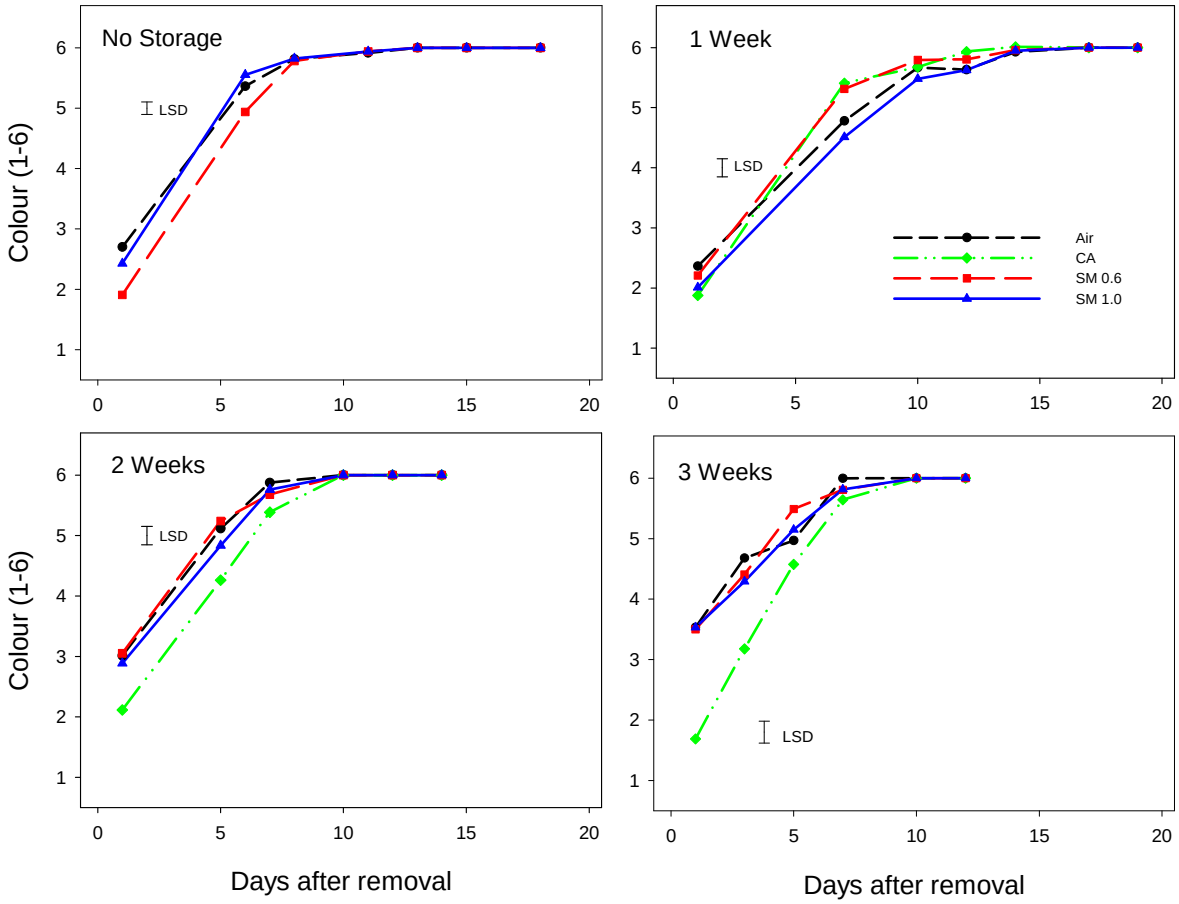


Figure 50 Skin colour (1 = green, 6 = yellow) of Calypso™ mango following treatment with either nil, 0.6 ppm, or 1.0 ppm of SmartFresh (SM), and with either no storage, or storage at 12°C for one, two or three weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide). Fruit were assessed at several intervals during ripening at 20oC. Refer to Table 102 for skin colour on removal from cold storage. LSD = least significant difference.

There was little effect of SmartFresh treatment on fruit firmness during ripening, either with no storage, or following 1-3 weeks cold storage (Figure 51). This suggests that SmartFresh had little effect on skin colour and softening changes during cold storage, compared with no SmartFresh treatment. Inconsistent SmartFresh effects on mango have been observed by others (Matt Adkins, AgroFresh, personal communication).

CA-treated fruit were generally softer during most ripening stages, with the difference between these treatments increasing with longer storage time.

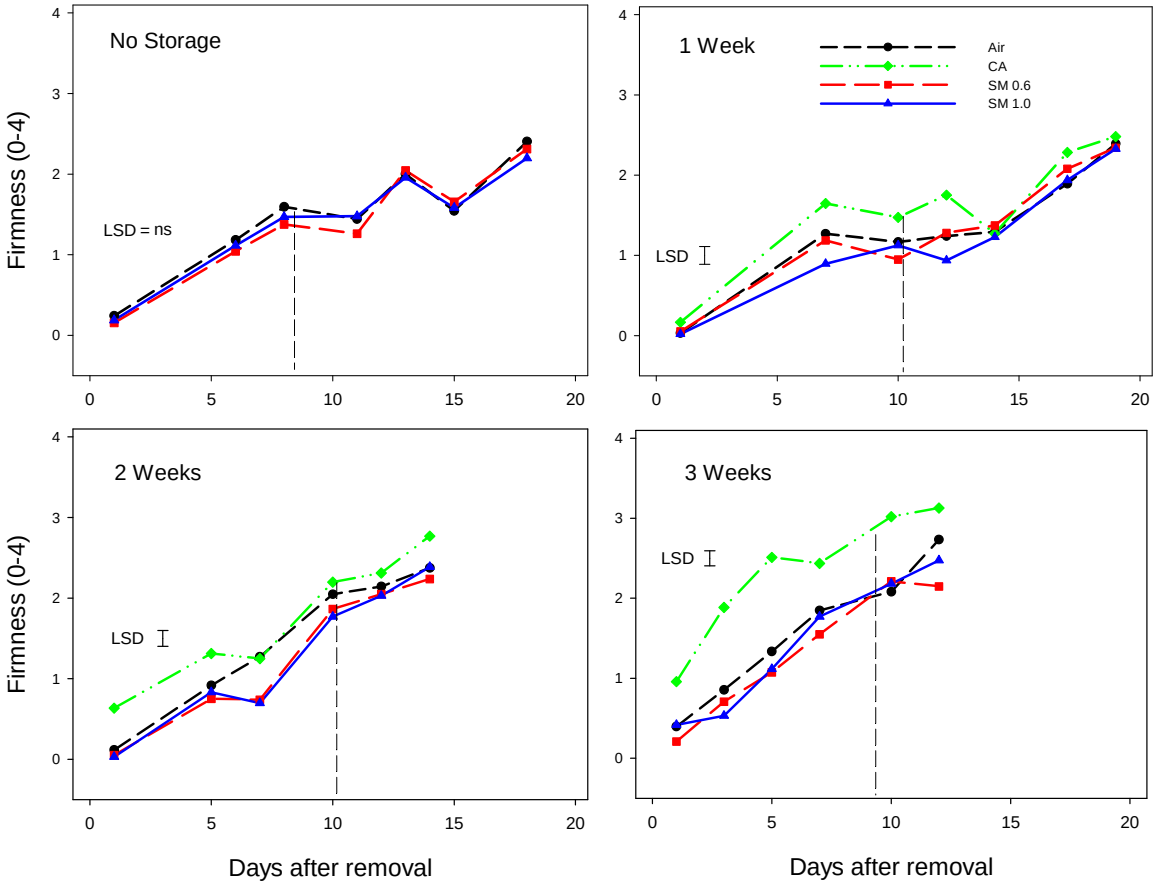


Figure 51 Fruit firmness (rated by hand on a scale of 0 = firm to 4= very soft) of Calypso^{TM} mango following treatment with either nil, 0.6 ppm, or 1.0 ppm of SmartFresh (SM), and with either no storage, or storage at 12°C for one, two or three weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide). Fruit were assessed at several intervals during ripening at 20oC. Vertical dashed line indicates approximate time fruit reached full yellow colour. Refer to Table 102 for firmness on removal from cold storage. Table LSD = least significant difference. ns = not significant.

At full colour, all fruit were at about the sprung firmness stage, except CA-treated fruit after three weeks of storage; these fruit were close to the soft stage. Therefore, with CA storage for three weeks, some customer/consumer training may be required because of the mis-conception that these fruit may be over-ripe.

7.3.2.3.2. Fruit quality at ripe

Fruit ripened 3-5 days quicker after one week storage, and 8-9 days quicker after two or three weeks storage compared with no storage (Table 103).There was little difference in ripening time between two and three weeks. For each storage duration, there was generally no difference in ripening time among treatments, except after one week storage where the higher SmartFresh treated fruit took two days longer to ripen than non-treated and air stored fruit.

Table 103 At ripe: External quality of ripe Calypso™ mango following treatment with either nil, 0.6 ppm, or 1.0 ppm of SmartFresh, and with either no storage, or storage at 12°C for one, two or three weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide). Fruit were ripened at 20oC and assessed 2-3 days after the full colour stage (skin colour rating of 6).

Treatment	Days to ripe (at 20°C)	Lenticel spotting (0-4)	Skin browning (0-4)	Stem end rots (0-4)	% Acceptable fruit*
No storage					
Control	18.7 a	1.4 gh	0.9 bcde	0.2 bcd	61 ab
SmartFresh 0.6	19.3 a	1.1 h	0.8 cdef	0.3 bcd	71 a
SmartFresh 1.0	19.3 a	1.3 gh	0.9 cde	0.1 d	77 a
1 week storage					
Air	14.0 c	1.6 fg	0.7 ef	0.4 abcd	58 abc
SmartFresh 0.6	15.0 bc	1.8 efg	0.8 cdef	0.3 bcd	58 abc
SmartFresh 1.0	16.0 b	2.0 de	1.2 ab	0.6 a	44 abcd
CA	14.0 c	1.1 h	0.6 f	0.3 bcd	70 a
2 weeks storage					
Air	10.7 d	2.3 bcd	0.6 ef	0.5 abcd	35 bcd
SmartFresh 0.6	11.3 d	2.0 def	1.3 a	0.5 abc	48 abcd
SmartFresh 1.0	11.3 d	2.6 ab	1.3 a	0.3 bcd	29 bcd
CA	11.3 d	2.6 ab	0.8 def	0.2 cd	46 abcd
3 weeks storage					
Air	10.7 d	2.2 cde	0.6 ef	0.7 a	34 bcd
SmartFresh 0.6	10.7 d	2.5 abc	1.1 abcd	0.7 a	24 d
SmartFresh 1.0	11.3 d	2.5 abc	1.1 abc	0.5 ab	28 cd
CA	11.3 d	2.9 a	0.7 ef	0.4 abcd	18 d
LSD	*1.9*	*0.43*	*0.31*	*0.35*	*33*

Means of 48 fruit per treatment.
Means in columns with different letters are significantly different (P<0.05) as tested by LSD.
For no storage fruit = days from harvest to ripe. For stored fruit = days from removal to ripe.
*Calculated as the percentage of fruit with no rots, or other individual defects as less than 3, or a combination of defects with a combined rating of less than 4.

At eating ripe, lenticel spotting was the main defect, followed by skin browning and rots (Table 103). Lenticel spotting severity generally increased with longer storage duration and with ripening (Figure 52). Storage treatment effects on severity were generally small, although there was significantly higher lenticel spotting severity with CA treatment after three weeks storage and ripening, compared to air storage.

Skin browning severity was in most cases higher in SmartFresh treated fruit compared with non-treated fruit, especially after two and three weeks storage (Table 103).

Stem end rots severity also generally increased with longer storage duration, but with little storage treatment effect (Table 103). Body rots severity was low or absent across all treatments (average severity = 0.15), and differences among treatments were not significant (data not shown).

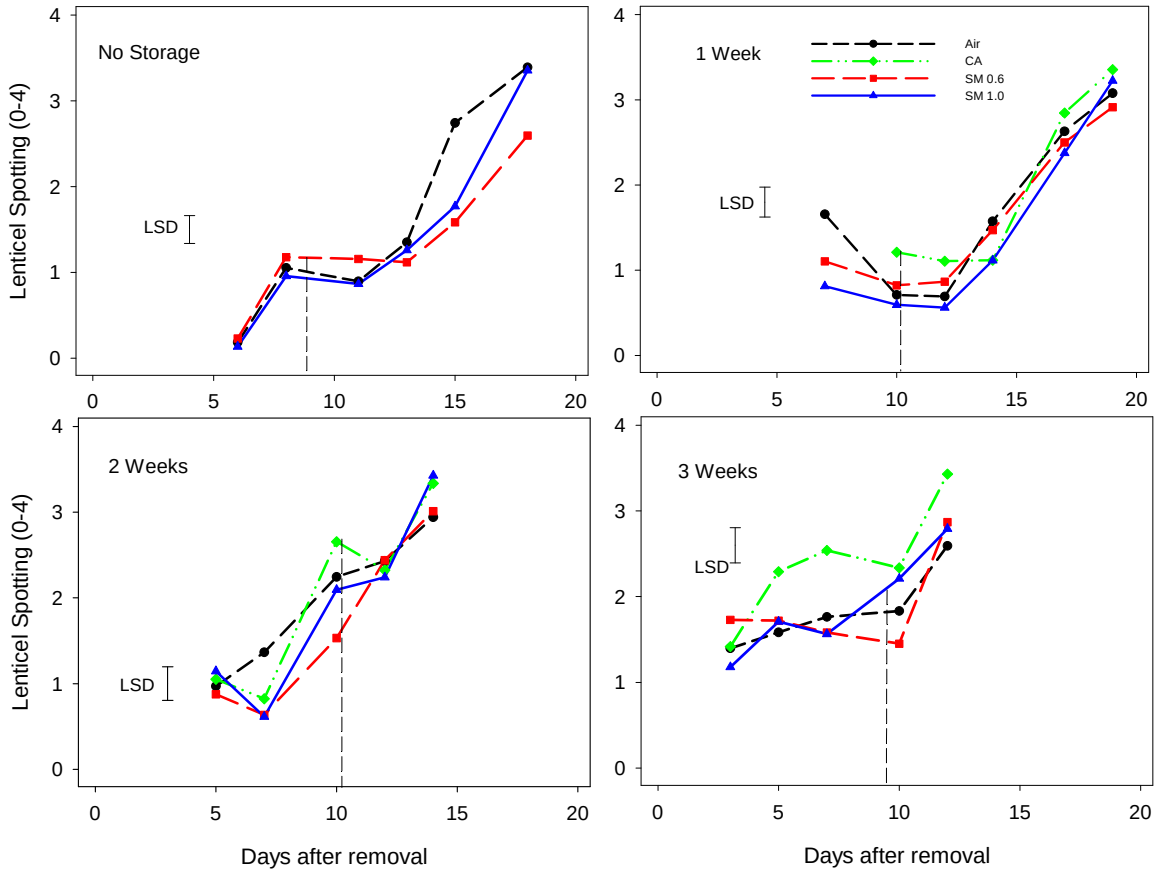


Figure 52 Lenticel spotting severity (rated on a scale of 0 = nil to 4 > 50%) of Calypso^{TM} mango following treatment with either nil, 0.6 ppm, or 1.0 ppm of SmartFresh (SM), and with either no storage, or storage at 12°C for one, two or three weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide). Fruit were assessed at several intervals during ripening at 20oC. Vertical dashed line indicates approximate time fruit reached full yellow colour. LSD = least significant difference.

There was generally no significant difference in the percentage of acceptable fruit among treatments within each storage duration (Table 103).

Lenticel spotting was the main contributor to reduced saleable life with longer storage. The percentage of acceptable fruit generally decreased with longer storage duration.

There were no significant treatment differences in flavour of ripe fruit after two weeks storage. The average flavour rating across all treatments was 5.3 (just above “neither like nor dislike”). This relatively low flavour rating was a combination of the early maturity of the fruit, and the length of cold storage.

Air 1 week

CA 1 week

Air 2 weeks

CA 2 weeks

Air 3 weeks

CA 3 weeks

Plate 43 Calypso™ mango at removal from storage at 12°C for 1, 2 or 3 weeks without (Air) or with controlled atmospheres (CA; 3% oxygen, 5% carbon dioxide).

7.3.2.4. Conclusions and recommendations

At removal

- CA storage (3% O_2, 5%CO_2) retarded the increase in yellow colour on the skin at removal from one, two and three weeks storage at 12°C compared with air storage or treatment with SmartFresh before storage.
- The treatment effect on skin colour was no longer evident after five days.
- CA stored fruit were generally softer at removal and at full colour, compared with air stored or SmartFresh-treated fruit.
- SmartFresh at 0.6 or 1.0 ppm had little effect on skin colour or firmness after storage, compared with air storage.

At eating ripe

- The percentage of acceptable ripe fruit was less after two or three weeks storage compared with one week storage, even with CA and SmartFresh treatment.
- Lenticel spotting was the main cause for decreased fruit acceptability with longer storage times, followed by skin browning and stem end rots.

CA storage retarded yellow skin colour development in stored Calypso™ mango, allowing fruit to be seafreighted for up to three weeks and arrive in a sufficiently backward state. These fruit will be softer at the full yellow colour stage, so customers/consumer education may be required to assure them that these fruit are not over-ripe.

Increased skin defects after longer storage, and consequent loss of fruit acceptability at eating ripe needs to be considered. Further understanding of the nature and development of lenticel spotting may help develop control measures to improve the appearance of the ripe fruit after storage.

7.3.3. Modified atmospheres

7.3.3.1. Introduction

We were approached by Amcor and One Harvest to assist in evaluating a new modified atmosphere film on Calypso™ mango.

Fruit were obtained from several growers in North Queensland, and placed into storage at the hard green stage. Half the green fruit were placed in MA bags and held at 12°C for 3, 4 and 5 weeks, while the other half were not placed in bags but held under the same conditions. At each removal, fruit firmness and colour were assessed, then the fruit were ripened under typical commercial conditions and again assessed for quality at the eating ripe stage.

Ripe fruit were also stored with or without modified atmospheres at 7°C for 3, 4 and 5 weeks. In a second trial, fruit were stored at 10 and 12°C for 3 or 4 weeks. The quality was assessed several days after removal from cold storage.

7.3.3.2. Materials and methods

7.3.3.2.1. Unripe fruit trial

Hard green Calypso™ fruit were supplied from Stewart Bros, packed on 15 Dec. The fruit were collected from La Manna in Brisbane on 19 Dec.

The fruit were transported to the laboratory at Nambour on the day of collection from La Manna. On arrival, the following treatments were applied:

- two treatments; non-bagged and bagged
- one storage temperature; 12°C

- three removal times; 3, 4, and 5 weeks
- six single tray replications per treatment
- total of 36 trays

One tray (12 fruit; total fruit mass of 4.5 kg) was placed in each bag, and another tray used for the non-bagged treatment. The fruit were placed at 12°C as soon as the bagging treatment was imposed. Oxygen (O_2) and carbon dioxide (CO_2) concentrations were measured 2 days after fruit were placed in bags, and then at weekly intervals thereafter, using a portable gas analyser. The analyser was calibrated using normal air as the reference.

At each removal time, the fruit were assessed as follows:

- The bags were opened and a typical tray of fruit photographed.
- The fruit were assessed for firmness and skin colour at removal from the cold storage.
- They were then treated with ethylene gas for 2 days at 10 ppm and 20°C, then held at 20°C until about 1-2 days before eating ripe.
- The fruit were then held at 12°C for 3-4 days, before ripening for a further 1-2 days at 20°C.
- Nine days after removal from cold storage (or when fruit had reached the eating soft stage), a typical tray was photographed, and each fruit assessed for skin colour, firmness and diseases, using the rating scales as outlined in Table 47. Flesh discolouration was rated as being present or absent.
- Flesh flavour was assessed by the postharvest team, and samples for Brix and acidity of the flesh taken (which are still being analysed.)

Table 104. Rating systems used for fruit firmness, lenticel spotting, skin browning, and rots of Calypso™ mango.

Rating	Hand firmness	Area of the skin affected		
		Lenticel spotting	Skin browning	All rots
0	Hard	Nil	Nil	Nil
1	Rubbery	To 10%	To 3cm^2	To 3cm^2
2	Sprung	To 25%	To 6 cm^2	To 6 cm^2
3	Soft	To 50%	To 25%	To 25%
4	Very soft	> 50%	> 25%	> 25%

7.3.3.2.2. Ripe fruit trial 1

Ripe Calypso™ fruit were grown by Patane, packed on 9 Dec (pallet 1002). The fruit were transported from Mareeba to Brisbane, and ripened under standard commercial conditions. The ripe fruit had an average softness of 2, skin colour about 5 (some mottled green), and were estimated to be about 2 days from eating ripe. On arrival at the laboratory, 6 fruit were placed in plastic trays and sealed within the MA bags. Another 6 fruit were held without being bagged. The fruit were about count 10, with total fruit mass per bag of about 2.7 kg.

The following treatments were applied:

- two treatments; non-bagged and bagged
- one storage temperature; 7°C
- three removal times planned; 3, 4, and 5 weeks
- six single tray replications per treatment

The fruit were held at 7°C. Removals at 3, 4, and 5 weeks were planned, but by week 3 the quality had deteriorated, so the week 4 and 5 samples were not assessed.

At 3 weeks, the fruit were removed from the bags and a typical tray photographed. Fruit were then assessed for firmness and colour, held at 20°C for about 3 days until fully ripe, and assessed for skin colour, firmness, disease and flavour as above.

7.3.3.2.3. Ripe fruit trial 2

In association with a cold storage trial, a further consignment of ripe fruit (grown by Lavers, packed on 15 Jan**),** were held at 10 and 12°C for 3 and 4 weeks. About 10 fruit were used per sampling unit, and the following treatments applied:

- two treatments; non-bagged and bagged
- two storage temperatures; 10 and 12°C
- two removal times planned; three, and either 4 or 5 weeks
- six single tray replications per treatment

The fruit were assessed several days after removal from cold storage, as in Trial 1.

Selected disease lesions were cultured on potato-dextrose agar and identified by the Fruit Pathology team at Indooroopilly.

7.3.3.3. Results

7.3.3.3.1. Unripe fruit trial

The O_2 concentrations averaged about 15%, and CO_2 about 6% throughout storage (Table 105). However, there was a big range between bags. Since similar fruit mass was placed in each bag, the range is likely a result of differing respiration rates between fruit, but unknown holes in the bags may also have contributed.

Table 105. Oxygen and carbon dioxide (CO2) concentrations in the modified atmosphere bags 2 days after placing Calypso™ mango fruit in the bags, and then approximately at weekly intervals thereafter. The gas concentrations for both the Unripe, and the Ripe fruit trial are presented.

Date	Unripe trial				Ripe trial			
	O_2		CO_2		O_2		CO_2	
	Average	Range	Average	Range	Average	Range	Average	Range
21-Dec	15.4	13.6-18.6	6.1	2.7-7.9	15.8	14.1-18.4	5.7	3.3-7.2
28-Dec	14.5	13.0-16.3	6.8	4.5-8.1	14.5	9.5-17.6	6.8	4.0-13.0
4-Jan	15.3	12.2-18.7	6.4	2.7-10.0	14.7	12.0-18.1	7.3	3.1-10.8
9-Jan	15.2	12.7-18.2	6.3	2.4-7.9	16.4	12.2-19.5	5.3	1.2-10.8
16-Jan	16.1	13.2-19.8	5.7	1.7-8.9	18.7	15.7-19.1	2.8	2.5-6.8
23-Jan	15.9	13.9-18.0	5.1	2.6-7.3				

MAP did not significantly affect firmness of the fruit at removal from cold storage (Table 106). With no MAP, the firmness was similar irrespective of the length of storage. With packaging, the fruit were softer with longer storage times.

MAP resulted in a slower loss of green colour, resulting in green fruit on removal (Table 106 and Plate 44).

These results are similar to those obtained with ‘Kensington Pride’ under cold storage or CA storage. It is generally more difficult to retard softening than skin colour development during cold storage, so that after storage there is a risk of fruit being soft and green.

At the eating soft stage, there was no MAP treatment effect on firmness (Table 107). All fruit were fully coloured, suggesting that MAP had little effect on shelf life after removal from cold storage.

There was also no significant MAP effect on body rots or dendritic spot. Flavour was slightly better in the MAP fruit, but this difference is unlikely to be commercially significant.

Table 106. The firmness (0=firm; 4=very soft) and skin colour (0=no yellow; 6=full yellow skin colour) at removal, of Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3, 4 and 5 weeks at 12°C. The means in columns within each category with different letters are significantly different (P< 0.05).

Storage time (weeks)	No MAP	With MAP
Firmness (0-4)		
3	1.5 bc	1.2 c
4	1.4 bc	1.2 c
5	1.6 ab	1.8 a
Skin colour (0-6)		
3	3.4 b	3.0 c
4	4.5 a	2.6 d
5	4.5 a	2.9 cd

Table 107. The firmness, and the average severity of dendritic spot, body rots and flavour of ripe Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3, 4, and 5 weeks at 12°C. The results within "Packaging" are averaged across the three storage times, and the results within "Storage" averaged across the two packaging treatments. The means in columns within "Packaging" and "Storage" with different letters are significantly different (P< 0.05).

Treatment	Severity Ratings (0-4)			Flavour (1-9)
	Firmness	Dendritic spot	Body rots	
Packaging				
Control				5.6 a
MAP				5.9 b
Mean	3.0	0.1	0.2	
Storage				
3 weeks	2.9 b		0.0 c	
4 weeks	3.0 a		0.1 b	
5 weeks	3.1 a		0.4 a	

MAP reduced lenticel spotting and skin browning only with longer storage (Table 108). There was no significant bagging effect on stem end rots severity, apart from after four weeks of storage, when no bagging resulted in more stem end rots.

With longer cold storage times, fruit were slightly softer nine days after removal, but this difference was small. There was no effect of storage time on skin colour of the ripe fruit. Lenticel spotting was slightly less severe with longer storage times using bags, while the effect on skin browning was inconsistent. Stem end rots increased with longer storage times in both bagging treatments.

Flesh discolouration was noted in the ripe fruit (Plate 45). This defect was similar to that responsible to the rejection of commercial consignments in Adelaide. MAP reduced the number of fruit affected after 4 and 5 weeks storage, and more fruit were affected with longer storage times (Table 109).

Table 108 The average severity of lenticel spotting, skin browning and stem end rots on ripe Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3, 4, and 5 weeks at 12°C. The results are the mean for each treatment. The means in columns within each defect category with different letters are significantly different (P< 0.05).

Storage time (weeks)	No MAP	With MAP
Lenticel spotting (0-4)		
3	0.79 [a]	0.73 [a]
4	0.45 [cd]	0.48 [bc]
5	0.73 [ab]	0.22 [d]
Skin browning (0-4)		
3	0.13 [b]	0.07 [bc]
4	0.02 [bc]	0.00 [c]
5	0.36 [a]	0.09 [bc]
Stem end rots (0-4)		
3	0.15 [b]	0.45 [b]
4	1.12 [a]	0.57 [b]
5	1.36 [a]	1.33 [a]

Table 109 The incidence (% of the fruit affected in relation to the total number of fruit per treatment) of flesh discolouration of ripe Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3, 4, and 5 weeks at 12°C.

Treatment	Time at 12°C		
	3 weeks	4 weeks	5 weeks
Control	0	13	29
MAP	0	0	13

7.3.3.3.2. Ripe fruit trial 1

Ripe fruit stored at 7°C developed extensive chilling damage (browning of the skin; Plate 46) after three weeks of storage, and the skin became rough and dehydrated. The flesh texture was very soft and watery, and flavour very flat. No further assessments of these fruit were conducted.

7.3.3.3.3. Ripe fruit trial 2

Fruit held at 10 and 12°C performed better than those held at 7°C in Trial 1, but still developed unacceptable chilling injury (average chilling injury severity above 2; Table 110). Chilling injury severity was less with MAP, and less at 12°C for 3 weeks compared with longer storage, or at 10°C (Table 111).

There was little lenticel spotting after 3 weeks, it but increased after 4 weeks (Table 110 and Table 111). At this time, 12°C storage resulted in the highest lenticel spotting severity. MAP reduced lenticel spotting after 4 weeks storage.

There was no MAP effect on body or stem end rots, but it reduced the severity of lenticel rots caused by *Cladosporium spp*. Body rots and dendritic spot were more severe with longer storage and higher storage temperatures (Table 110 and Table 111).

There was no consistent effect of MAP on flesh discolouration (data not shown), but it was slightly worse with 10°C storage (Table 110).

Table 110 The severity (0-4) of chilling injury to the skin, body rots, stem end rots, lenticel rots (caused by Cladosporium spp), and flesh discolouration of ripe Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3 or 4 weeks at 10 or 12°C. The fruit were ripe when placed into storage, then assessed several days after removal from storage. The results are averaged across the other treatments when there was no significant interaction between the treatments. Where there are no results presented, the treatment interactions were significant, and the detailed results are presented in Table 111. The means in columns with different letters within each defect and treatment are significantly different at P<0.05.

Treatment	Severity (0-4)				
	Chilling injury	Body rots	Stem end rots	Lenticel rots	Flesh discol.
MAP					
No	3.1 [a]			1.3 [a]	
Yes	2.1 [b]			0.8 [b]	
Mean		0.2	0.5		
Storage time					
3 weeks			0.3 [b]		
4 weeks			0.7 [a]		
Storage temperature					
10°C					0.1 [a]
12°C					0.0 [b]

Table 111 The severity (0-4) of lenticel spotting, chilling injury to the skin, body rots, stem and dendritic spot of ripe Calypso™ mango fruit with or without being held in modified atmosphere bags, and stored for 3 or 4 weeks at 10 or 12°C. The fruit were ripe when placed into storage, then assessed several days after removal from storage. The results are presented for those treatments that showed significant interactions. The means in columns with different letters within each defect are significantly different at P<0.05.

Treatment	Severity (0-4)	
	Weeks storage	
	3	4
Lenticel spotting		
MAP		
No	0.1 [c]	1.9 [a]
Yes	0.0 [c]	1.4 [b]
Storage temperature		
10°C	0.0 [c]	1.3 [b]
12°C	0.1 [c]	2.0 [a]
Chilling damage		
Storage temperature		
10°C	2.9 [a]	2.9 [a]
12°C	1.8 [b]	2.7 [a]
Body rots		
Storage temperature		
10°C	0.0 [c]	0.2 [b]
12°C	0.0 [bc]	0.6 [a]
Dendritic spot		
Storage temperature		
10°C	0.5 [c]	1.2 [b]
12°C	0.6 [c]	2.0 [a]

Before storage

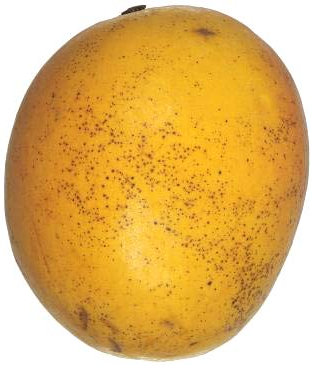
No modified atmosphere	With modified atmosphere	
		At removal from 3 weeks storage
		At removal from 5 weeks storage
		Five weeks storage; at ripe

Plate 44.Unripe fruit trial. Fruit stored without bags and with bags, for three or five weeks, either at removal from cold storage, or at ripe.

Body rots (anthracnose)

Stem end rot

Dendritic spot



Lenticel spotting

Lenticel rots

Flesh discolouration

Plate 45. Defects on ripe fruit.

Plate 46. Ripe fruit trial. Fruit stored without bags and with bags for three weeks, either at removal from cold storage photo on the left), or at ripe. There was little effect of bags on outturn quality.

7.3.4. Conclusions and recommendations

Green fruit

- Modified atmosphere packaging (MAP) did not retard fruit softening during storage for 3-5 weeks, but did retard loss of skin green colour. This resulted in more soft, green fruit with packaging, but the green skin colour was completely lost by the time the fruit were at the eating soft stage.
- MAP did not increase the shelf life after removal from cold storage.
- Body rots and dendritic spot were not affected by MAP, while stem end rots were lower with MAP after 4 weeks cold storage only.
- MAP also reduced lenticel spotting and skin browning after 5 weeks, but there was no difference after 3 or 4 weeks storage. MAP also reduced flesh discoloration, particularly after longer cold storage.
- Most of the rots, and flesh discoloration increased with longer cold storage.
- In summary, the main effects of MAP were on flesh discoloration, and possibly a small reduction in lenticel spotting and skin browning after 5 weeks storage.

Ripe fruit

- Cold storing ripe fruit for 3 weeks or longer resulted in severe chilling injury at removal. MAP slightly reduced chilling injury, but it was still unacceptable.
- MAP also reduced lenticel spotting and lenticel rots slightly, but the reduction was relatively small.
- As expected, chilling injury was less at higher temperatures and for shorter durations. Stem end rots were more severe with longer storage temperatures, and both body rots and dendritic spot were more severe at lower temperatures, and for longer durations at 12°C.

The results suggest that there may be a small benefit to MAP as used in the current experiments for hard green Calypso™ mango fruit. Further trials may be warranted, but given the small benefit at this stage, careful consideration of the possible commercial benefits needs to be considered against the costs and other challenges associated with using modified atmosphere bags.

Cold-storing ripe Calypso™ mango fruit for 3 weeks or longer does not seem advisable due to the high risk of chilling damage.

8. Market access

8.1. VHT submission to AQIS for Japan

Five varieties of Australian mangoes are currently permitted to be exported to Japan following a vapour heat treatment developed against Queensland fruit fly (*Bactrocera tryoni*), Mediterranean fruit fly (*Ceratitis capitata*) and Asian Papaya fruit fly (*Bactrocera papayae*: eradicated from mainland Australia in 1998) (Corcoran *et al*. 1997, Heather *et al*. 1997, Corcoran *et al*. 1998).

Several experiments verified the efficacy of the current vapour heat treatment against *B. tryoni* in Calypso™ mango. Mature eggs of *B. tryoni* were used in this trial as previous research had identified mature eggs of *B. tryoni* as being at least as heat tolerant as any other stage of *B. papayae* and *C. capitata* (Corcoran *et al*. 1997, Heather *et al*. 1997).

Research was undertaken using a Sanshu-Sangyo EHK-1000D pilot-scale vapour heat treatment system located at the DEEDI disinfestation laboratory in Cairns. Artificially infested mangoes of 'Kensington Pride' and Calypso™ were treated simultaneously. The fruit were heated to a core temperature of 41°C to 47°C and then water cooled until the core temperature of fruit was ≤ 35°C.

The detailed report is presented in Appendix 2. In summary, the results showed that there is no significant difference in the heat response of *B. tryoni* eggs when heated in either 'Kensington Pride' or Calypso™ mango. To verify the results from the comparative trials, five large scale confirmatory trials against mature eggs of *B. tryoni* in Calypso™ mangoes were undertaken. Infested fruit were heated until the core temperature of all probe fruit was 47.0°C for 15 minutes. Fruit was then water cooled until the core temperature of fruit was ≤ 35°C. No survivors were recorded from an estimated 70,320 treated insects. These treatments had no negative effect on external or internal fruit quality.

This report has been submitted to the Biosecurity Australia for use in future negotiations on the use of VHT for Calypso™ mangoes.

8.2. Review on mango fruit responses to irradiation

A literature review on the responses of mango fruit to irradiation was conducted in 2009 (Appendix 3). The key findings are:

- Several mango cultivars are damaged by irradiation at disinfestation doses, including 'Kensington Pride' and 'B74'. Symptoms include lenticel damage and skin browning, and delayed loss of green colour during ripening. 'Honey Gold' is not affected.
- Cultivars which can maintain lenticel integrity during fruit expansion, and which have a smaller lenticel cavity and better cuticle coverage of the lenticel, generally have less lenticel damage. This has not been confirmed with Australian cultivars.
- In 'B74', lenticel damage usually involves brown discolouration around the lenticels. It is not clear why or how these pigments develop. Theories include sap "leaking" from the adjacent latex vessels toward the lenticels causing browning, and the browning being a defence mechanism against contaminants entering the lenticel cavity and surrounding cells. Understanding these mechanisms could help predict whether, for example, withholding irrigation before harvest could reduce lenticel damage.
- Field factors such as rain and humid conditions before harvest contribute to lenticel damage, but other unknown field factors are also involved since farm differences exist in dry production areas.

- Commercial picking and packing practices increase lenticel sensitivity to irradiation. Water seems to be a common factor in these operations, but it is not clear why water might increase sensitivity. Eliminating water from these processes will reduce irradiation damage but this may not be practical. Further research is required.
- Also other postharvest practices such as holding temperatures, fruit coatings and antioxidants to prevent brown pigment development may help reduce irradiation damage.

8.3. Irradiation 2007/8

8.3.1. Introduction

Disinfestation treatments are required for marketing in southern Australian states, and also for export markets such as New Zealand and the USA. Irradiation is a potentially useful disinfestation treatment against fruitfly and seed weevil in mango that can be used for these markets.

Trial shipments of irradiated Calypso mango to New Zealand developed skin damage, which appears to be associated with cell damage around the lenticels. Given the importance of irradiation treatment for the New Zealand and US markets, ways to minimise quality loss from irradiation need to be developed.

The condition of the fruit before treatment might affect fruit response to irradiation (Wall 2008). Likely factors include harvesting/packhouse systems, fruit temperature, time after harvest and condensation on the fruit during treatment. These may act partly through cell turgor pressure (e.g. cells hard and full of water, or "soft and spongy"), which can affect cell sensitivity to physical/chemical stress. Post-irradiation conditions may also be a factor, but are likely to be less important.

In the present trial, Calypso^{TM} fruit were harvested from three blocks on two farms in the Bundaberg/Childers area. The fruit were irradiated at different times after harvest (differing ripeness stages), and with various fruit temperature regimes before and after treatment. The fruit were irradiated at standard commercial dosage rates, then ripened at 20°C and assessed for quality.

8.3.2. Materials and methods

8.3.2.1. Plant material and treatments

CalypsoTM mango fruit were obtained on 28-29 January from three separate blocks on two farms in the Bundaberg/Childers area. They were either harvested directly from the trees into trays without any exposure to water or detergent, or collected from the end of the packing line (commercially picked and packed). Fruit from one of the farms were picked, packed and treatments imposed on the same day of harvest, while fruit from the other farm was packed and treated the day after harvest (standard commercial practice for that farm).

Treatments were imposed to test whether the following affected irradiation response:

- harvest and packing practices (especially exposure to water and detergent)
- ripeness stage at treatment
- cold storage before treatment
- skin/pulp temperature and presence of condensation on the skin at treatment
- cold storage treatment immediately after irradiation
- combination of cold storage before and after treatment.

The treatments are outlined in Table 112.

8.3.2.2. Quality assessment

Fruit quality was assessed at 13 days after arrival in the lab (13 or 14 days after harvest, depending on their origin) for all treatments, and then at the eating soft stage for each treatment. The rating scales in Table 113 were used. The background skin colour was rated using the following scale:

1 = 0-10% yellow
2 = 10-30% yellow
3 = 30-50% yellow
4 = 50-70% yellow
5 = 70-90% yellow, and
6 = 90-100% yellow.

This rating refers to the percentage of the background skin colour (non-red) area showing yellow and not the percentage of the whole skin area.

Fruit were considered to be saleable if there were no rots, or other individual defects were less than severity 3, or all combination of defects had a combined rating of 4 or less.

After treatment and storage (where required), fruit were ripened at 20°C and assessed for quality.

Fruit samples were irradiated on 30 January at a commercial plant in Brisbane (Steritech Pty Ltd). The mean dosage used was 369 Gy (ranging from 275 to 465 Gy).

Table 112 Harvesting, ripening and cold storage treatments applied with or without irradiation to Calypso^{TM} mango fruit.

Treatment	Details
1. Off tree + Eth 1d, no irrad	Harvested straight from the tree into trays (no further postharvest/packhouse treatment). Fruit held at 23°C with ethylene for 1 day.
2. Off tree + Eth 1d, irrad	As above, but irradiated
3. 16^{o}C 1d, irrad	To simulate irradiation immediately after harvest
4. Eth 1d, irrad	Irradiation one day after the start of ripening
5. Eth 3d, irrad	Irradiation three days after the start of ripening
6. Eth 2d, no irrad	Control for treatments 4-5
7. 10^{o}C 2 d, 22^{o}C 1d, irrad	Stored at 10°C for two days then 20°C for one day to allow skin and pulp temperature to increase before irradiation
8. 10^{o}C 2.5 d, irrad	As above, but fruit removed from 10°C just before irradiation (low skin/pulp temperature and condensation on the skin)
9. 10^{o}C 2.5 d, no irrad	As for treatment 8, but no irradiation. Control for treatments 7-8.
10. Eth 1 d, irrad, 12 ^{o}C 2d	Ripen for one day, irradiate, then store for two days at 12°C before ripening
11. Eth 1 d, no irrad, 12 ^{o}C 2d	As for treatment 10, but no irradiation.
12. 10^{o}C 2 d, 22^{o}C 1d, irrad, 12^{o}C 2d	As for treatment 10 but held at 10°C for two days before irradiation
13. 10^{o}C 2 d, 22^{o}C 1d, no irrad, 12^{o}C 2d	As for treatment 12, but no irradiation

Table 113 Rating scales used for quality assessment

Rating	Rots	Skin browning	Sapburn	Lenticel damage
0	Nil	Nil	Nil	Nil
1	To 3cm^2	To 3cm^2	To 3cm^2	To 10%
2	To 6 cm^2	To 6 cm^2	To 6 cm^2	To 25%
3	To 25%	To 25%	To 25%	To 50%
4	> 25%	> 25%	> 25%	> 50%

3cm^2 is the size of a 5 cent piece
12cm^2 is the size of a 20 cent piece

8.3.3. Results

The ripening and cold storage treatments affected the days from harvest at eating soft, as expected (Table 114). Irradiation slowed down ripening by 1-2 days in most treatments where direct comparisons between +/- irradiation could be made. Irradiation prevented the development of full yellow colour on the ripe fruit (retained some green colour), despite the fact that the fruit often took longer to ripen (Plate 47).

There was virtually no lenticel spotting or skin browning on fruit harvested directly from the tree (Table 115, Plate 48), and in fact irradiation slightly reduced lenticel spotting on the ripe fruit. Irradiation significantly increased lenticel spotting and skin browning in all non-stored treatments (compare Eth 2d with Eth 1 and Eth 3d; Plate 49) and in some stored treatments (Plate 50). The stage of ripeness at irradiation appeared to have no effect on these defects.

Table 114 At eating soft: Effect of ripeness stage and cooling before and after treatment, and irradiation on the days to eating soft, and skin colour at ripe of CalypsoTM mango.

Fruit handling	Irradiation	
	No	Yes
Days from removal to ripe		
Off tree + Eth 1d	13 ^{e}	12 ^{f}
16 ^{o}C 1d		15 ^{d}
Eth 1 d		14 ^{e}
Eth 2d	8 ^{g}	
Eth 3d		8 ^{g}
10 ^{o}C 2 d, 22 ^{o}C 1d		16 ^{c}
10 ^{o}C 2.5 d	17 ^{b}	18 ^{a}
Eth 1 d, Irrad, 12 ^{o}C 2d	14 ^{d}	16 ^{c}
10 ^{o}C 2 d, 22 ^{o}C 1d, Irrad, 12 ^{o}C 2 d	17 ^{b}	18 ^{a}
Skin colour (1-6)		
Off tree + Eth 1d	6.0 ^{abc}	5.8 ^{bcd}
16 ^{o}C 1d		5.8 ^{abcd}
Eth 1 d		5.5 ^{e}
Eth 2d	6.0 ^{abc}	
Eth 3d		5.7 ^{cde}
10 ^{o}C 2 d, 22 ^{o}C 1d		5.5 ^{e}
10 ^{o}C 2.5 d	6.0 ^{ab}	5.8 ^{abcd}
Eth 1 d, Irrad, 12 ^{o}C 2d	6.0 ^{a}	5.7 ^{de}
10 ^{o}C 2 d, 22 ^{o}C 1d, Irrad, 12 ^{o}C 2d	6.0 ^{ab}	5.7 ^{de}

Means of 36 fruit per treatment (12 fruit per treatment per rep).
For each quality attribute, means with different letters are significantly different (P<0.5) as tested by LSD.

Any form of cold treatment either before or after irradiation significantly increased lenticel spotting and skin browning, even without irradiation (Table 115). This suggests that seasonal factors resulted in the fruit being very sensitive to holding conditions irrespective of the irradiation treatment. Irradiation treatment increased lenticel spotting only in the cold treatment before and after irradiation. However, irradiation increased skin browning in all of these cold treatments. Skin browning was the most severe when cold fruit with condensation on the skin were irradiated, but this treatment had no additional effect on lenticel spotting compared to the other cold treatments.

Irradiation did not significantly affect stem end rots severity in any of the treatments, and only in one of the treatments did irradiation reduce body rots severity (Table 115).

Irradiation did not affect percentage of saleable fruit when harvested directly into trays (Table 116). However, irradiation reduced percentage saleable fruit in the non-cold treatments by 40-60% compared with no irradiation. Cold treatment itself also reduced percentage of saleable fruit, while irradiation did not significantly reduce percent saleable fruit in these cold treatments. The major defects contributing to loss in percent saleable fruit was lenticel spotting and skin browning.

Fruit harvested directly into trays had lower percentage saleable fruit compared with ethylene treatment (Ethylene 1 d) because of no fungicide treatment in the Off tree treatment.

Not irradiated

Irradiated

Plate 47 Commercially harvested and packed Calypso^{TM} mangoes, held at 10°C for two days before irradiation. Irradiation increased lenticel spotting/skin browning. Thirteen days after harvest.

Table 115 The severity of lenticel spotting, skin browning, and rots on ripe Calypso™ mango fruit following irradiation. Fruit were treated at different ripeness pages, and also after and/or before calling for two days.

Fruit handling	Irradiation	
	No	Yes
Lenticel spotting (0-4)		
Off tree + Eth 1d	0.6 [f]	0.2 [g]
16 °C 1d		2.9 [bcd]
Eth 1 d		2.1 [e]
Eth 2d	1.0 [f]	
Eth 3d		2.6 [d]
10 °C 2 d, 22 °C 1d		2.9 [bcd]
10 °C 2.5 d	2.8 [bcd]	3.3 [ab]
Eth 1 d, Irrad, 12 °C 2d	3.1 [abc]	3.5 [a]
10 °C 2 d, 22 °C 1d, Irrad, 12 °C 2 d	2.7 [cd]	3.5 [a]
Skin browning (0-4)		
Off tree + Eth 1d	0.7 [e]	0.7 [e]
16 °C 1d		2.1 [bc]
Eth 1 d		1.5 [d]
Eth 2d	0.5 [e]	
Eth 3d		1.3 [d]
10 °C 2 d, 22 °C 1d		2.3 [b]
10 °C 2.5 d	1.6 [d]	3.4 [a]
Eth 1 d, Irrad, 12 °C 2d	1.6 [cd]	2.3 [b]
10 °C 2 d, 22 °C 1d, Irrad, 12 °C 2 d	1.7 [cd]	2.6 [b]
Stem end rots (0-4)		
Off tree + Eth 1d	0.1 [cd]	0.2 [bcd]
16 °C 1d		0.4 [abcd]
Eth 1 d		0.3 [abcd]
Eth 2d	0.1 [d]	
Eth 3d		0.1 [d]
10 °C 2 d, 22 °C 1d		0.6 [abc]
10 °C 2.5 d	0.6 [abc]	0.5 [abcd]
Eth 1 d, Irrad, 12 °C 2d	0.7 [ab]	0.3 [bcd]
10 °C 2 d, 22 °C 1d, Irrad, 12 °C 2 d	0.5 [abcd]	0.8 [a]
Body rots (0-4)		
Off tree + Eth 1d	0.1 [b]	0.1 [b]
16 °C 1d		0.0 [b]
Eth 1 d		0.0 [b]
Eth 2d	0.0 [b]	
Eth 3d		0.1 [b]
10 °C 2 d, 22 °C 1d		0.0 [b]
10 °C 2.5 d	0.4 [a]	0.0 [b]
Eth 1 d, Irrad, 12 °C 2d	0.0 [b]	0.0 [b]
10 °C 2 d, 22 °C 1d, Irrad, 12 °C 2 d	0.1 [b]	0.0 [b]

Table 116 Effect of irradiation, stage of ripeness and cooling before and after treatment on percentage of saleable Calypso™ mango fruit at the ripe stage.

Fruit handling	Irradiation	
	No	Yes
Percentage of saleable fruit[1]		
Off tree + Eth 1d	60 ^{def}	69 ^{ef}
16 °C 1d		20 ^{abc}
Eth 1 d		45 ^{cde}
Eth 2d	82 ^{f}	
Eth 3d		40 ^{bcd}
10 °C 2 d, 22 °C 1d		22 ^{abc}
10 °C 2.5 d	25 ^{abc}	6 ^{a}
Eth 1 d, Irrad, 12 °C 2d	14 ^{ab}	8 ^{a}
10 °C 2 d, 22 °C 1d, Irrad, 12 °C 2 d	28 ^{abc}	15 ^{ab}

[1] percentage of fruit with no rots, or other individual defects were less than severity 3, or all combination of defects had a combined rating of 4 or less.

Not irradiated

Irradiated

Plate 48 Calypso™ mango fruit harvested from the tree directly into trays (no contact with water of detergent, and no postharvest fungicide treatment). Irradiation did not increase lenticel spotting/skin browning. Thirteen days after harvest.

Not irradiated

Irradiated

Plate 49 Commercially harvested and packed Calypso™ mangoes after 2-3 days ethylene with no cooling. Irradiation increased lenticel spotting/skin browning severity. Ten days after harvest.

Non-irradiated

Irradiated

Plate 50 Cooling before irradiation. Irradiation increased skin damage. Twenty days after harvest.

Microscopy revealed that the damage to the lenticels was due to dark pigments in the cells surrounding the lenticels (Plate 51-Plate 52).

Plate 51 Typical skin damage caused by irradiation

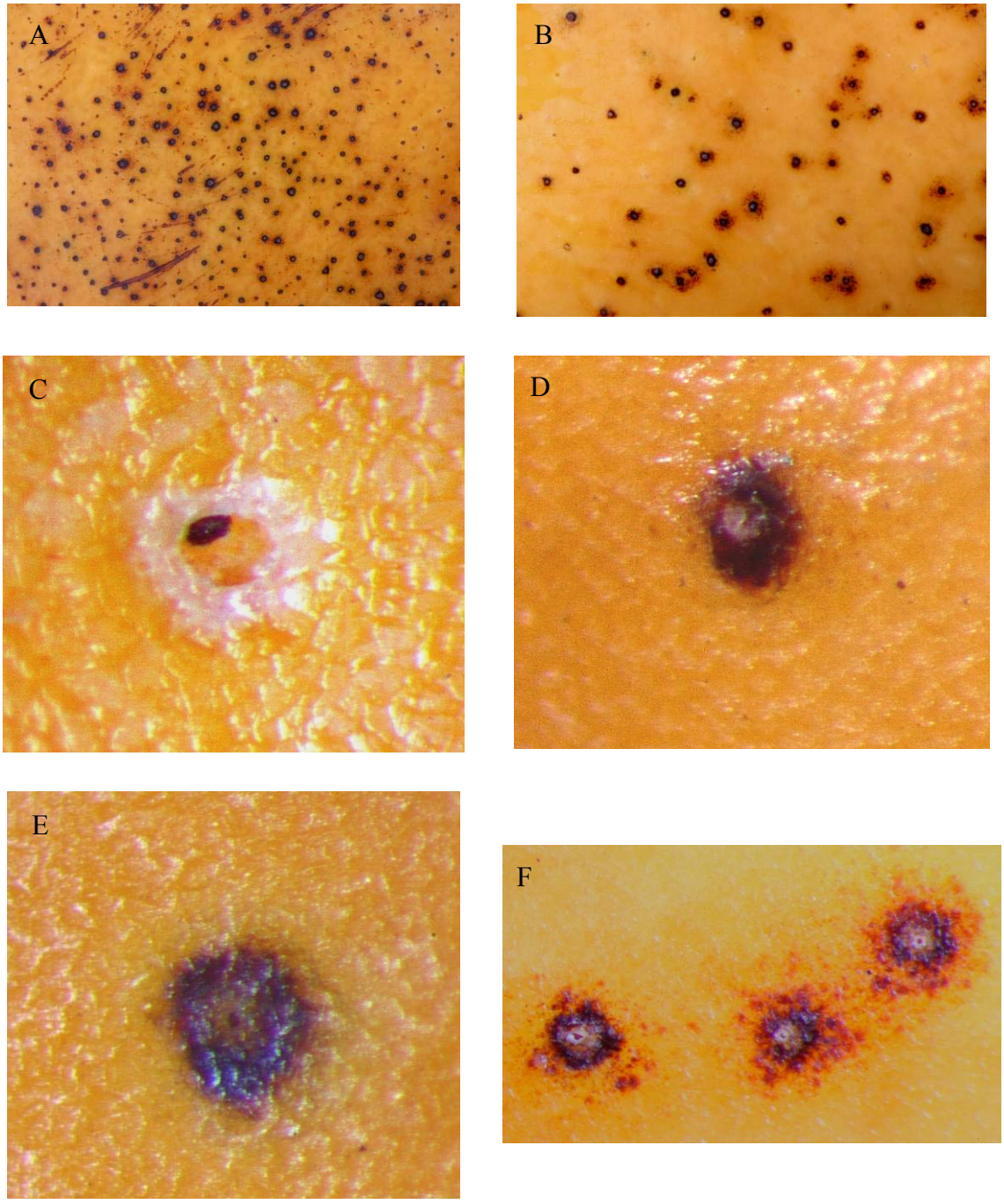


Plate 52 Characteristics of lenticels on irradiated Calypso™ mango: A,B= general damage symptoms; C=undamaged lenticel and D-F=increased damage severity following irradiation.

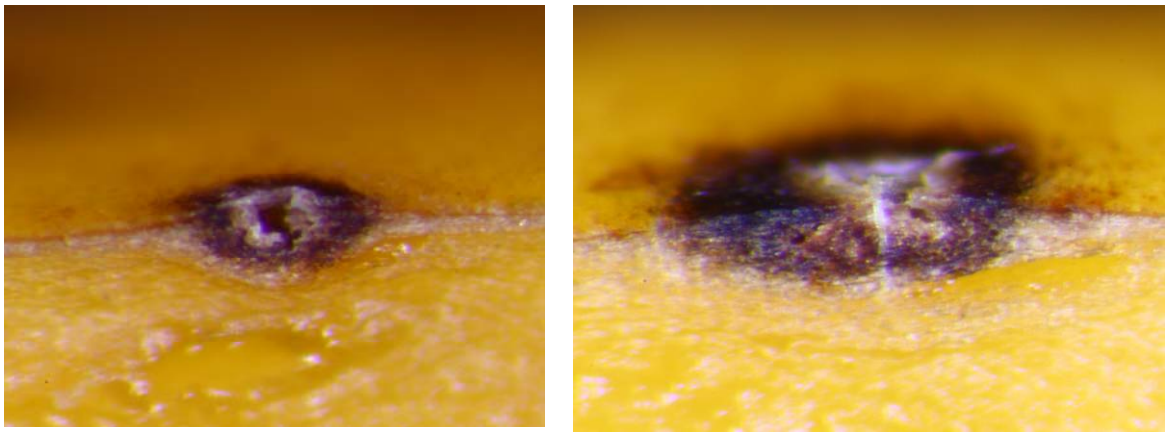


Plate 52 cont. Characteristics of lenticels on irradiated Calypso™ mango. Section through the lenticel into the skin of the fruit:

8.3.4. Conclusions and recommendations

- When fruit were harvested directly into trays without contact with water or detergent, irradiation did not reduce the quality of ripe fruit.
- In all other treatments (fruit obtained from the end of the packing line), irradiation significantly reduced visual quality, mainly because of increased lenticel spotting and skin browning.
- Cold treatments before or after irradiation also increased lenticel spotting and skin browning even without irradiation. This suggests greater fruit sensitivity to cold treatments than in previous years.
- Irradiation also retarded ripening and loss of green skin colour.
- There were no indications that stage of ripeness affected irradiation response.
- Of the cold treatments, only irradiating cold fruit with condensation on the skin increased irradiation damage compared with the other cold treatments.
- The lenticel damage appeared to be due to production of dark pigments in the cells around the lenticels. The discoloration penetrated several cell layers into the skin.

Further research is required to identify factors contributing to, and ways of reducing irradiation damage. This research could include:

- Identifying what harvesting/packhouse practices contribute to damage. We suspect that exposure to water/detergent is the main contributing factor.
- Can treatments such as fruit waxing reduce the negative impacts of water exposure.

This was a major focus of the 2008/9 research programme.

8.4. Irradiation 2008/9

8.4.1. Introduction

The research reported in the previous section indicated that irradiation was the main cause, and that harvesting and packing procedures significantly increase the sensitivity of lenticels to irradiation damage. Given the potential benefits of an effective irradiation protocol, further work was carried out to identify the causes of irradiation damage, and effective commercial treatments.

The lenticels on mature mango fruit originate from the fully functional stomata on very young fruit (du Plooy *et al.* 2006). As the mango fruit grows, the cells of the stomata can not keep pace with the increasing fruit surface area, and lose function.

In this report we have used the term "lenticel damage" rather than lenticel spotting. In our experience, there are several forms of lenticel "abnormality":

- lenticel spotting, which shows as a very small light grey "spot", presumably caused by a slight "woody" growth of the cells around the lenticel.
- Lenticel discolouration, where a green or red halo develops around the lenticel. This is usually caused by a lack of de-greening, or the accumulation of red pigments around the lenticel.
- Lenticel damage, where there is obvious production of wound-related pigments, such as brown discolouration as occurs in bruised apple, avocado, potato etc. This discolouration is likely associated with oxidation of phenolic compounds.

Two trials are reported here. The first trial, using Calypso™ mango fruit from three farms in the NT, looked at which parts of the commercial harvesting and packing process contribute to skin damage. This expanded on the 2007/8 work that commercially picked/packed fruit were far more sensitive to irradiation than fruit taken straight from the tree. The second trial, using fruit from three separate blocks on two farms in the Bundaberg area, studied whether skin damage could be reduced by treating fruit at different ripeness stages. Fruit were either harvested and packed directly into trays after de-sapping, or harvested and packed as per normal commercial practices. Fruit were then irradiated 1-11 days after harvest. A minimum dosage rate of 400 Gy was used, which is the requirement for access into the US market.

8.4.2. Materials and methods

8.4.2.1. Trial 1

Calypso™ mango fruit were obtained from three farms in the Northern Territory on 29-30th October 2008. Fruit were collected as follows (see Table 117 for more details):

1. Directly from the tree, de-sapped on racks then placed into trays (no exposure to water or detergents)
2. From the field bins at the harvest aid
3. After brushing in the packhouse
4. At the end of the packing line.

Fruit harvested directly from the tree, de-sapped on racks for one hour without any exposure to water or detergent, then either only:

5. Dipped into the same water used in the harvest aid (minus detergent) for 90 seconds, then air dried
6. Placed by hand at the beginning of the brushes in the pack house, and collected at the end of the brushes, or
7. Placed over the insecticide/fungicide spray, and collected at the end of the drying tunnel.

Two trays per grower/replication were collected for each of the above. One tray of each was irradiated, and the other was used as a control. Fruit samples were irradiated at a commercial plant in Brisbane (Steritech Pty Ltd) using gamma irradiation from a Cobalt 60 source. The mean dosage used was 543 Gy (ranging from 441 to 701 Gy). A minimum dose of 400 Gy was required.
Fruit were assessed for firmness, colour, lenticel damage and skin browning as in the previous trial, on arrival at the postharvest lab and directly before irradiation treatment. Firmness, colour, lenticel damage and skin damage were assessed the day after irradiation treatment then every two to three days thereafter for both control and treated fruit. Quality of all trays was assessed at full yellow colour, and again six days later. The end of saleable life was recorded for each tray. Fruit were considered still saleable if there were no rots, or other individual defects were less than severity 3, or all combination of defects had a combined rating of 4 or less.

Table 117 Harvesting and handling treatments applied with or without irradiation to Calypso™ mango fruit from the Northern Territory.

Treatment	From tree	Harvesting		Transport	Brushes	Fungicide	Packing
		Water	Detergent				
1. Off tree	■						
2. Harv Aid		■	■				
3. Harv aid+brushes		■	■	■	■		
4. End of packing line		■	■	■	■	■	■
5. Water only		■					
6. Brushes only					■		
7. Fungicide only						■	

8.4.2.2. Trial 2

Calypso™ mango fruit were obtained on 28 January 2009 from three separate blocks on two farms in the Bundaberg area (south east Queensland). They were either harvested directly from the trees, de-sapped on racks and packed into trays without exposure to water or detergent, or collected from the end of the packing line (commercially picked and packed). Treatments are outlined in Table 118.

8.4.3. Results

8.4.3.1. Trial 1

Irradiation retarded loss of green skin colour by approximately 6 days (Figure 53), and the irradiated fruit remained in the transitional green-yellow stage for longer. They also had a more patchy green-yellow appearance during this stage, further reducing visual appeal. Irradiation slightly retarded softening in the early ripening stages, but not to the same extent as colour change. This resulted in greener fruit at the same firmness stage.

Irradiation significantly reduced visual quality by increasing lenticel damage from three days after treatment onwards (Figure 53). Non-irradiated fruit needed another approximately 10 days to reach the same severity. This suggests that irradiation causes very rapid "aging" of the lenticels. The nature of the lenticel damage was similar to that observed in the previous season trial, with significant brown discolouration around the lenticels in severe cases.

The lenticels on fruit harvested with no exposure to water or brushing were not significantly affected by irradiation (Figure 53; Plate 54). Presumably, water and possibly physical treatments increased lenticel sensitivity to damage from irradiation.

The severity of lenticel damage increased progressively as the fruit passed through the harvesting and packing stages, irrespective of whether the fruit were irradiated or not. However, the effects of

harvesting/packing on lenticel damage were far greater with irradiation. Sampling at the end of the harvest aid alone was sufficient to increase lenticel damage severity on ripening fruit to a severity rating 2, sufficient to reduce saleability.

Table 118 Harvesting and ripening treatments applied with or without irradiation to Calypso^{TM} mango fruit. Fruit were treated with 10ppm ethylene at 20oC for two days then ripened to differing stages at 20oC before irradiation. DAH = days after harvest, T = harvested directly from the tree into trays, and C = commercially picked and packed.

Treatment code	Days between harvest and treatment	Colour stage at treatment	Off tree	Commercial	Irradiated
1 DAH – T	1	1	√		√
4 DAH – T	4	2-3	√		√
6 DAH – T	6	3-4	√		√
8 DAH – T	8	4-5	√		√
11 DAH – T	11	6	√		√
1 DAH – C	1	1		√	√
4 DAH – C	4	2-3		√	√
6 DAH – C	6	3-4		√	√
8 DAH – C	8	4-5		√	√
11 DAH – C	11	6		√	√
Control – T			√		
Control – C				√	

Fruit samples were irradiated at the same commercial plant as in Trial 1. The mean dosages and range used for each treatment are described in Table 119.

Table 119 Dosages used for irradiation of Calypso^{TM} mango fruit. . DAH = days after harvest, T = harvested directly from the tree into trays, and C = commercially picked and packed.

Treatment	Average dosage (Range) (Gy)
1 DAH - T, 1 DAH - C	628 (580-770)
4 DAH - T, 4 DAH - C	610 (560-690)
6 DAH - T, 6 DAH - C	610 (530-670)
8 DAH - T, 8 DAH - T	526 (458-582)
11 DAH - T, 11 DAH - C	564 (one dosimeter only)

Fruit were assessed as per Trial 1.

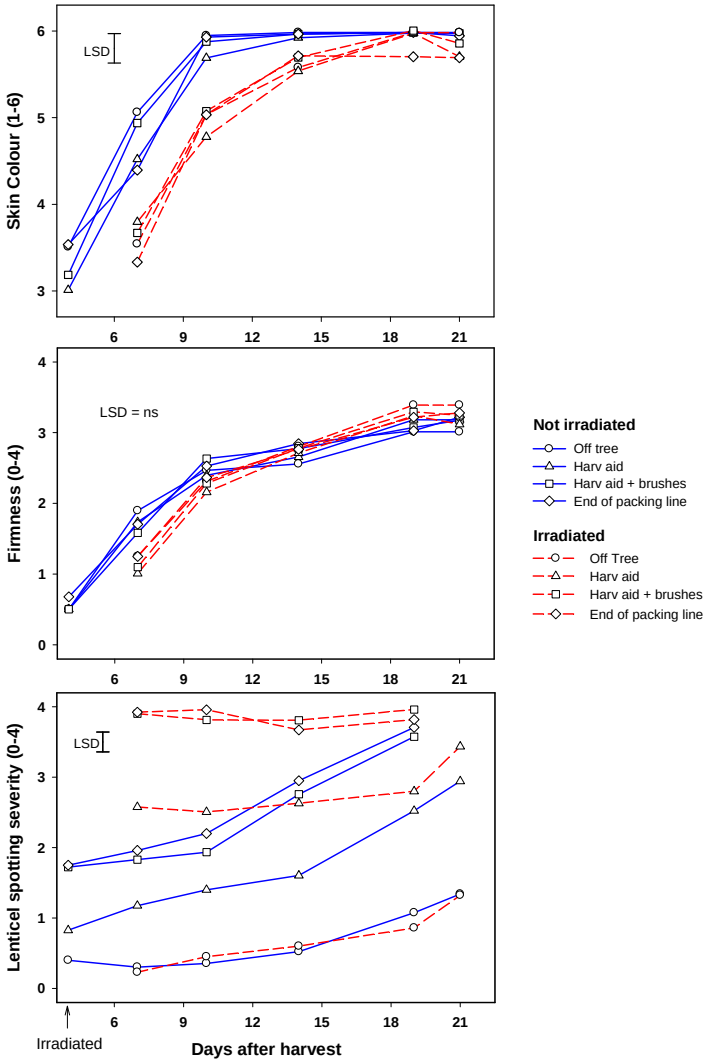


Figure 53 The development of skin colour, firmness, and severity of lenticel damage in Calypso^{TM} mango fruit sampled at varying stages in the harvest and packing process, as affected by irradiation treatment.

Without irradiation, lenticel damage severity increased at each sampling point, with the major increase occurring after the harvest aid and after brushes (Table 120). Exposure to the harvest aid water only (excluding detergent) did not increase lenticel damage, but brushes only and insecticide/fungicide only did. These results are similar to previous Calypso^{TM} studies, where lenticel damage severity gradually increases with sampling through the picking/packing process.

With irradiation, a similar pattern occurred, but to a far greater degree (Table 120). All major picking/packing operations increased lenticel damage severity by 1.4-2 severity units. The biggest increase occurred when sampled after the harvest aid + brushes. Even exposure to the harvest aid water only (minus detergent) increased lenticel damage severity with irradiation.

To a lesser degree, irradiation also increased the severity of skin browning at eating ripe (Table 120).

These results suggest that irradiation rapidly ages the lenticels. Picking/packing practices probably make the lenticels more sensitive to further "challenge" by irradiation, thus increasing damage.

Table 120 At eating ripe. The severity of lenticel damage and skin browning on ripe Calypso™ mango fruit sampled at varying stages in the harvest and packing process as affected by irradiation treatment.

Fruit handling	Severity (0-4)			
	Lenticel spotting		Skin browning	
	No irradiation	Irradiation	No irradiation	Irradiation
Off tree	0.3 ^{h}	0.4 ^{h}	0.1 ^{c}	0.6 ^{a}
Harv Aid	1.2 ^{de}	2.6 ^{b}	0.0 ^{c}	0.6 ^{a}
Harv aid + brushes	1.8 ^{c}	3.8 ^{a}	0.0 ^{c}	0.6 ^{a}
End of packing line	2.0 ^{c}	3.7 ^{a}	0.0 ^{c}	0.7 ^{a}
Water only	0.5 ^{gh}	1.4 ^{d}	0.0 ^{c}	0.6 ^{a}
Brushes only	0.9 ^{ef}	2.0 ^{c}	0.1 ^{c}	0.3 ^{b}
Insecticide/fungicide only	0.8 ^{fg}	2.0 ^{c}	0.1 ^{c}	0.7 ^{a}

Means within columns with letters are significantly different (P≤0.05) as tested by LSD.

Severity = based on the visual assessment of the surface area affected (0=nil; 4=more than 50%).

8.4.3.2. Trial 2

8.4.3.2.1. External fruit quality during ripening

As in Trial 1, irradiating fruit that were harvested from the tree directly into trays did not increase lenticel damage severity (Plate 53) while fruit that had been commercially picked and packed, then irradiated, developed significant lenticel damage.

Delaying irradiation until fruit was partially ripe reduced lenticel damage in commercially packed fruit (Figure 54). The longer the delay between harvest and irradiation (the more ripe the fruit), the less severe the lenticel damage after irradiation. Fruit irradiated one, four and six days after harvest displayed the most adverse effects to irradiation, and developed unacceptable levels of lenticel damage more quickly post-irradiation (usually within two days) than fruit treated at a more ripe stage (Plate 55 and Plate 56). Fruit irradiated at eight and 11 days after harvest (colour stages 4-5 and 6) still had increased lenticel damage compared to non-irradiated fruit, however the effect was less pronounced and developed more gradually than fruit irradiated at one, four and six days after harvest (colour stages 1, 2-3 and 4 respectively).

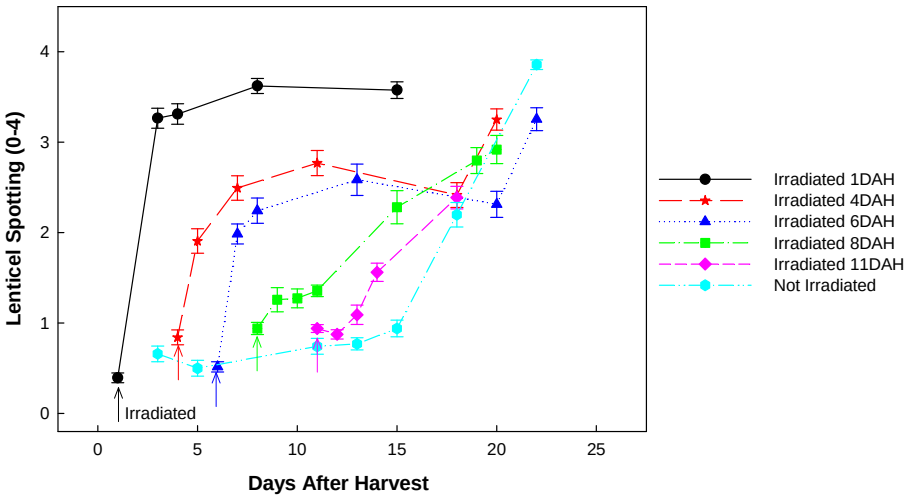


Figure 54 The severity of lenticel damage on Calypso™ mango fruit commercially harvested and packed. Fruit were either ripened at 20oC (not irradiated) or irradiated at 1, 4, 6, 8, and 11 days after harvest (DAH) and then ripened at 20oC. For the irradiated treatments, data is displayed on the graph from the day the fruit were irradiated as indicated by arrows.

In most cases, irradiation increased skin browning severity in fruit commercially harvested and packed (Figure 55). As with lenticel damage, skin browning was generally worse in fruit treated early during the ripening process. All but those irradiated one day after treatment were still at acceptable levels 20 days after treatment.

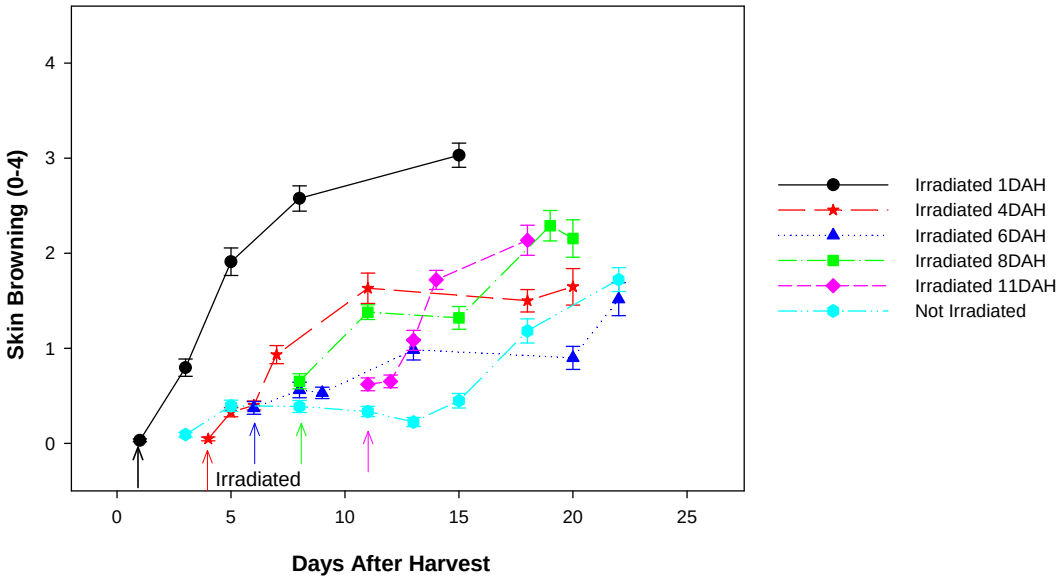


Figure 55 The severity of skin browning on Calypso™ mango fruit commercially harvested and packed. Fruit were either ripened at 20oC (not irradiated) or irradiated at 1, 4, 6, 8, and 11 days after harvest (DAH) and then ripened at 20oC. For the irradiated treatments, data is displayed on the graph from the day the fruit were irradiated as indicated by arrows.

The response of skin colour to irradiation was similar to Trial 1 (Figure 56). Yellow colour development was usually delayed when irradiated up to six days after harvest. Later irradiation had no impact on skin colour development.

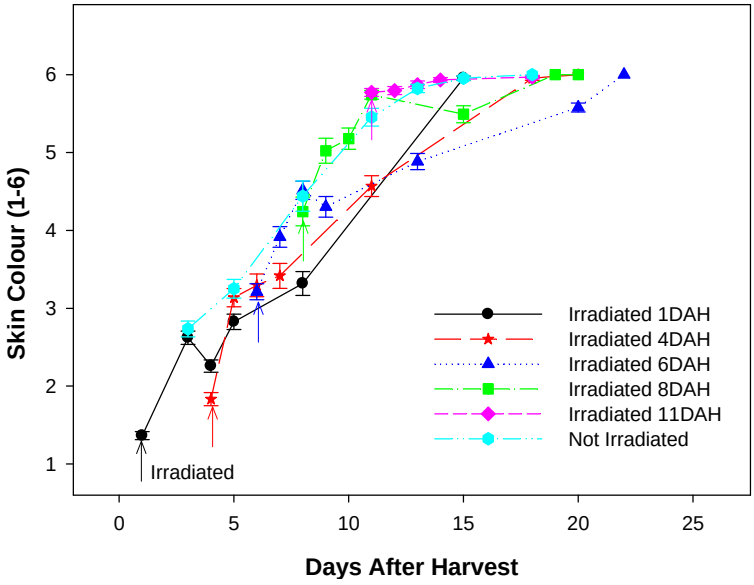


Figure 56 The percentage of the skin with yellow colour on Calypso™ mango fruit commercially harvested and packed. Fruit were either ripened at 20oC (not irradiated) or irradiated at 1, 4, 6, 8, and 11 days after harvest (DAH) and then ripened at 20oC. For the irradiated treatments, data is displayed on the graph from the day the fruit were irradiated as indicated by arrows.

There was little effect of irradiation on external quality during ripening in fruit harvested directly into trays (without contact with water, detergent, brushes, or chemical treatment), regardless of what stage of ripening they were irradiated (data not shown; Plate 55).

8.4.3.2.2. External fruit quality at full colour

Irradiation delayed the days for the fruit skin to reach full colour (a key indicator of when the fruit are ripe) by up to six days compared with no irradiation for most treatments (Table 121). The delay was statistically significant when irradiated up to six days after harvest, compared with no irradiation. There was little delay in colour when fruit was irradiated 11 days after harvest. There was little difference in days to full colour between fruit collected directly from the trees or at the end of the packing line.

Similar results of retarded ripening and loss of green colour in Calypso™ were reported in our previous studies.

Table 121 The days from harvest to full colour and firmness (0-4) of Calypso™ mango fruit full colour (90-100% of the skin with yellow). The fruit were harvested from the tree directly into trays ('off tree') or commercially harvested and packed ('end of packing line'), irradiated at 1, 4, 6, 8, and 11 days after harvest (DAH), and then ripened at 20oC.

Treatment	Days to full colour		Firmness (0-4)	
	Off tree	End of packing line	Off tree	End of packing line
Control	14.0 ^{de}	14.7 ^{cde}	1.5 ^{e}	1.2 ^{g}
1 DAH	16.0 ^{abcde}	16.0 ^{abcde}	2.4 ^{b}	2.5 ^{ab}
4 DAH	20.3 ^{a}	19.0 ^{abc}	2.4 ^{ab}	2.2 ^{c}
6 DAH	20.0 ^{ab}	20.7 ^{a}	2.1 ^{c}	2.6 ^{a}
8 DAH	17.0 ^{abcde}	18.7 ^{abcd}	2.0 ^{cd}	1.9 ^{d}
11 DAH	13.7 ^{e}	15.3 ^{bcde}	1.4 ^{ef}	1.3 ^{fg}
LSD	*4.9*		*0.2*	

Means for either days to full colour or firmness with different letters are significantly different (P≤0.05) as tested by LSD.

Irradiation treatments generally resulted in softer fruit at the full colour stage compared with not irradiated, except when treated 11 days after harvest (Table 121). This suggests that irradiation have the greater effect in slowing the loss of green colour, than softening. The differences in firmness between off tree and end of packing line fruit was usually small or inconsistent.

All irradiation treatments significantly increased lenticel damage severity at full colour in "end of packing line" fruit (Table 122). Fruit irradiated one day after harvest had the most severe damage, while irradiating ripe fruit (11 DAH) resulted in the lowest lenticel damage severity. The fact that irradiation dosage was the lowest for the 11 DAH fruit may have contributed to these results. However, even when the dosages were similar (e.g., four and six days after harvest), lenticel damage decreased from four to six DAH. This suggests that sensitivity to irradiation decreases as fruit ripen. The causes for this requires further investigation.

Irradiation of fruit collected directly from the trees ('off tree') also increased lenticel damage severity when treated 4-8 days after harvest, but not as severely as 'end of packing line' fruit (Table 122). For each treatment, the severity of lenticel damage in 'end of pack line' fruit was 2-7 times higher than in 'off tree' fruit.

All irradiation treatments also significantly increased skin browning severity at full colour (except off tree 11 days after harvest; Table 122). Generally, severity was higher when irradiated 1-4 days after harvest.

Irradiation did not significantly affect body rots or stem end rots severity at full colour (data not shown). Across all treatments, the average severity ratings were very low (0.03 for body rots and 0.2 for stem end rots).

Table 122 Severity (0-4) of lenticel damage and skin browning, and the % of saleable fruit of Calypso™ mango fruit at full colour (90-100% of the skin with yellow). The fruit were harvested from the tree directly into trays ('off tree') or commercially harvested and packed ('end of packing line'), irradiated at 1, 4, 6, 8, and 11 days after harvest (DAH), and then ripened at 20oC.

Treatment	Lenticel spotting severity (0-4)		Skin browning severity (0-4)		% of saleable fruit	
	Off tree	End of packing line	Off tree	End of packing line	Off tree	End of packing line
Control	0.2 ^{g}	0.9 ^{e}	0.2 ^{g}	0.6 ^{f}	93 ^{a}	92 ^{a}
1 DAH	0.5 ^{fg}	3.6 ^{a}	0.8 ^{ef}	3.0 ^{a}	90 ^{ab}	6 ^{e}
4 DAH	1.3 ^{d}	2.4 ^{c}	1.2 ^{cd}	1.5 ^{c}	73 ^{abcd}	48 ^{bcde}
6 DAH	0.7 ^{ef}	2.8 ^{b}	0.9 ^{ef}	0.9 ^{de}	76 ^{abc}	33 ^{de}
8 DAH	0.7 ^{ef}	2.3 ^{c}	0.6 ^{f}	2.0 ^{b}	77 ^{abc}	45 ^{cde}
11 DAH	0.2 ^{g}	1.5 ^{d}	0.3 ^{g}	1.4 ^{c}	88 ^{abc}	70 ^{abcd}
LSD	*0.3*		*0.3*		*43*	

Means for either defect or for the percentage of saleable fruit with different letters are significantly different (P≤0.05) as tested by LSD.

Severity = based on the visual assessment of the surface area affected (0=nil; 4=more than 50%).

% of saleable fruit = percent of fruit with no rots, a severity rating below 3 for lenticel damage and skin browning, or when the sum of both defects was 4 or below.

As a result of the high severity of lenticel damage and, to a lesser degree, skin browning, most irradiation treatments (except 11 days after harvest) significantly reduced the percentage of saleable fruit at full colour of the "end of packing line" fruit (Table 122). In contrast, the percentage of "off tree" saleable fruit was not affected by irradiation.

Off tree – Not irradiated

Off tree – Irradiated

End of packing line – not irradiated

End of packing line – Irradiated

Plate 53 Calypso™ mango fruit harvested from the tree directly into trays ('off tree') or commercially harvested and packed ('end of packing line') as affected by irradiation seven days after treatment. There was very little increase in lenticel damage with irradiation of fruit harvested directly from the tree (no exposure to commercial practices). In contrast irradiation damage occurred with fruit taken from the end of the packing line.

Off tree – 7 days after harvest (Control – T)

Off tree – 17 days after harvest (Control – T)

Plate 54 Fruit harvested from the tree straight into trays without exposure to water or detergent. Not irradiated. Note the absence of lenticel damage on the fruit.

Off tree irradiated (1 DAH – T)

End of packing line irradiated (1 DAH – C)

Plate 55 Effects of irradiation 1 day after harvest on Calypso^{TM} mango fruit (three days after treatment). Irradiation did not increase lenticel damage/skin browning in fruit harvested from the tree directly into trays ('off tree' - no contact with water or detergent, and no postharvest fungicide treatment). When fruit from the end of packing line ('commercial') were irradiated 1 day after harvest, unacceptable levels of skin damage were evident three days after treatment.

Not irradiated (Control – C)

Irradiated 1 day after harvest (1 DAH – C)

Irradiated 4 days after harvest (4 DAH – C)

Irradiated 6 days after harvest (6 DAH – C)

Irradiated 8 days after harvest (8 DAH – C)

Irradiated 11 days after harvest (11 DAH – C)

Plate 56 Effect of irradiation on Calypso^{TM} mango fruit harvested collected at the end of the packing line. Seven days after treatment.

8.4.4. Conclusions and recommendations

Trial 1

- Irradiation retarded loss of green skin colour during ripening by about six days and resulted in fruit with reduced visual appeal during ripening process (patchy green-yellow appearance).

- Irradiation only slightly retarded softening in the early ripening stages, resulting in greener fruit at the same firmness stage.
- Irradiation significantly reduced visual quality by increasing lenticel damage from three days after treatment onwards. Non-irradiated fruit needed another 10 days to reach the same severity, suggesting rapid "aging" of the lenticels caused by irradiation.
- Lenticel damage severity increased progressively as the fruit passed through the harvesting and packing stages, and this effect was much greater in irradiated fruit.
- Lenticel damage severity on fruit harvested directly from trees into trays were not significantly affected by irradiation, suggesting that exposure to water, physical and/or chemical treatments increased lenticel sensitivity to irradiation.
- The effects of sampling stage on severity were similar without or with irradiation, so that maximum severity for each treatment occurred with fruit sampled after harvesting and brushes or at the end of the packing line.
- Exposure to only the water used in the harvest aid (minus detergent) was sufficient to increase lenticel sensitivity to irradiation. Brushing itself and fungicide/insecticide treatments also increased lenticel sensitivity, and to greater degree than water only.
- To a lesser extent, irradiation also increased skin browning severity at eating ripe.

Trial 2

<u>During ripening</u>

- Irradiation at 1-8 days after harvest delayed the days from harvest to full colour by 2-6 days.
- Delaying irradiation until the fruit were partially ripe reduced lenticel damage during ripening in fruit that were commercially harvested and packed. This may have allowed the lenticels to partially recover from "stresses" induced during picking and packing.
- Fruit irradiated 1-6 days after harvest were more severely affected, and developed unacceptable levels of lenticel damage more quickly post-irradiation (usually within two days) than fruit treated at a more ripe stage (8-11 days after harvest).

<u>At the full colour (ripe) stage</u>

- Irradiation treatments (except 11 days after harvest) generally resulted in softer fruit compared with no irradiation.
- All irradiation treatments significantly increased lenticel damage (and skin browning to a lesser degree) in commercially picked/packed fruit. Fruit irradiated one day after harvest had the most severe damage, followed by 4-8 days after harvest, while fruit irradiated 11 days after harvest had the least severe damage.
- Irradiation treatments (except 11 days after harvest) significantly reduced the % of saleable commercially picked/packed fruit from 92% to 6-48% depending on the stage of ripeness at irradiation.
- Irradiation had little effect on quality or saleability of ripe fruit that had been picked directly from trees into trays.

So far, the results suggest that the only way to achieve acceptable Calypso^{TM} mango quality after irradiation is to either hand pick the fruit directly into trays, or irradiate only ripe fruit. Both options present significant commercial challenges.

Further research is required to identify factors contributing to, and ways of effectively reducing, irradiation damage. This research could include:

- The effect of treatments aimed at reducing skin damage after irradiation, such as:
- Fruit coatings to prevent oxygen access to the lenticel cells and thereby reduce browning
- Pre-irradiation anti-oxidant treatments to prevent the formation of the brown pigments
- Pre-conditioning heat treatments to make the skin less sensitive to irradiation
- Isotonic solutions in harvest aids and packing lines to reduce the uptake of water into the lenticel cells

- More detailed analysis of the nature of lenticel damage, and why water itself increases lenticel sensitivity
- The effect of lower doses, as accepted by New Zealand and hopefully interstate.
- Presently, irradiation is not recommended as a viable disinfestation treatment for Calypso™ mangoes due to the high skin sensitivity to lenticel damage after treatment.

8.5. Irradiation 2009/10

8.5.1. Introduction

Marketing mangos to areas such as southern Australia, New Zealand and the USA requires disinfestation treatments to reduce the risk of quarantine pests such as fruit fly and mango seed weevil. Irradiation is a potential disinfestation treatment for mangoes which may allow greater access to these markets.

In trials conducted over the last few years, irradiation of commercially picked and packed B74 mango fruit at doses over 300 Gy resulted in skin damage. The main symptoms were lenticel damage, and to a lesser extent, skin browning. Fruit that were not exposed to picking/packing procedures before irradiation did not develop these symptoms.

Further investigation was required to evaluate fruit response to a broader dose range, as disinfestation requirements for different marketing regions range from 150 to 400 Gy. Further studies were also needed to understand the mechanisms behind increasing lenticel sensitivity. Previous studies have shown that damage can be reduced by irradiating partially ripe fruit, or fruit that have been harvested and packed straight from the tree. Research in 2008/09 showed that B74 fruit exposed to solutions such as harvest aid detergent and postharvest sprays had greater lenticel sensitivity to irradiation damage, but it was not clear whether water alone caused the increased sensitivity, or contaminants in the water. Exposure to wet brushing alone also increased fruit damage after irradiation. These results suggest that fruit sensitivity can be manipulated, however better understanding of skin sensitivity is required to help develop commercially useful solutions. In addition, lenticel damage is thought to be a browning reaction which usually requires oxygen to oxidise phenolic compounds in the skin. The application of carnauba wax-based fruit coating slightly reduced lenticel spotting in non-irradiated B74 mango fruit in a previous trial, presumably by decreasing exposure of the skin to oxygen. Thus, the potential for waxing to reduce irradiation damage was investigated further.

To evaluate the impact of these areas on fruit response to irradiation, several trials were conducted during the 2009-10 mango season. The fruit were irradiated at Steritech (a commercial irradiation facility near Brisbane), and special racks were designed to minimise the dose range and to increase accuracy in achieving the target dose. The dose response evaluation included three runs to fine-tune the accuracy of the irradiation facility and to test the responses of fruit from different growing areas. To test the effects of water on lenticel damage, fruit were dipped in deionised water, bore water, harvest aid solution or 0.9% salt solution for 0-120 seconds before irradiation. The impact of brushes and waxing on fruit response to irradiation was tested by either sampling fruit directly from the trees, or placing them on a packline brush unit with and without water, or at the end of the packing line with or without the application of carnauba-based wax before irradiation. After irradiation, the fruit were ripened at 20°C and the quality assessed at regular intervals.

8.5.2. Materials and methods

8.5.2.1. Dose response

8.5.2.1.1. Fruit and treatments

B74 fruit were obtained on three occasions (Runs) from the Northern Territory and North Queensland and from three farms (replications) within each region (except Run 2) (Table 123). Fruit were either

sampled directly from the tree and desapped on racks with no contact with water or Mango Wash (off tree), or commercially harvested (using Mango Wash) and sampled from the field bin at the packhouse (from bin), or taken from the end of the pack line (end packline) (Table 124). One 10 kg tray (25 fruit) was used for each replication and treatment.

Table 123 Source and harvest dates of B74 mango used in three Runs to determine fruit response to irradiation.

Location	Farm/Replicate	Harvest date
Run 1: mid-season NT		
Darwin, NT	Acacia Hills Farm	5/11/2009
Katherine, NT	Oolloo Farms K2	5/11/2009
Mataranka, NT	Oolloo Farms	5/11/2009
Run 2: early-season NQ		
Dimbulah, NQ	Oolloo Farms	6/12/2009
Dimbulah, NQ	Blushing Acres	6/12/2009
Dimbulah, NQ	Blushing Acres	7/12/2009
Run 3: late-season NQ		
Dimbulah, NQ	Oolloo Farms	6/01/2010
Mareeba, NQ	Stewart Brothers	6/01/2010
Mutchilba, NQ	Patane	6/01/2010

Fruit for Runs 1 and 2 were air freighted to Brisbane within 36 h of harvest, and held at Maroochy Research Station (MRS) at 12°C until about 6 h before irradiation (seven, and 3-4 days after harvest, respectively). Fruit for Run 3 were road freighted to Gatton (near Brisbane) at 12-14°C, then held at MRS at 12°C until irradiation (five days after harvest).

8.5.2.1.2. Irradiation

Fruit were irradiated at Steritech Pty Ltd (a commercial irradiation facility near Brisbane) using gamma irradiation from a Cobalt 60 source. Four dosimeters (Opti-chromic detectors FWT-70-40 M) were placed in each tray one fruit in from the corners to monitor doses. Trays were covered with 4 mm plywood lids with a 15 mm low density foam lining to prevent fruit movement (Plate 57). Trays were placed on their side in a rack designed to fit on 1 m high bins used for irradiating other products. This ensured more consistent doses between trays of the same treatment.

After irradiation, fruit were transported to MRS and ripened at 20°C. Fruit from Run 1 received 10 ppm ethylene for three days after irradiation, and Run 3 fruit received 10 ppm ethylene for one day.

Table 124 Harvesting and irradiation treatments applied to B74 mango fruit. Off tree = fruit harvested by hand, desapped on racks in the field, then hand packed. From bin = fruit collected from the field bins at the packhouse after commercial harvesting, then hand packed. End packline = fruit commercially picked and packed and sampled from the end of the pack line.

			Irradiation dose (Gy)	
Run no.	**Irradiation date**	**Fruit sample point**	**Target**	**Actual received (average and min.-max.)**
1	12/11/2009	Off tree	0	0
			400	254 (217-304)
		End packline	0	0
			150	75 (47-125)
			250	181 (148-213)
			400	196 (125-254)
2	10/12/2009	From bin	0	0
			400	764 (685-840)
		End packline	0	0
			150	373 (313-428)
			300	593 (529-675)
			400	711 (653-772)
3	11/01/2010	End packline	0	0
			150	218 (171-263)
			300	393 (336-437)
			400	378 (332-433)
			600	479 (414-515)

Plate 57 Tray and rack system for irradiation of B74 mango. (A) Trays were covered with ply lids with foam. (B) Trays placed vertically in racks (four trays per rack). (C) Racks placed on top of bins.

8.5.2.1.3. Quality assessment

The B74 Quality Assessment Manual (Hofman *et al.* 2010) rating systems were used. The background skin colour was rated using the following scale:

1 = 0-10% yellow
2 = 10-30% yellow
3 = 30-50% yellow
4 = 50-70% yellow
5 = 70-90% yellow
6 = 90-100% yellow

The rating refers to the percentage of the background skin colour (non-red) area showing yellow and not the percentage of the whole skin area.

Firmness was rated using hand pressure as follows:

0 = Hard (no 'give' in the fruit)
1 = Rubbery (slight 'give' in the fruit)
2 = Sprung (flesh deforms by 2-3 mm with extreme thumb pressure)
3 = Firm soft (whole fruit deforms with moderate hand pressure)
4 = Soft (whole fruit deforms with slight hand pressure)

A 0-5 rating scale was used for lenticel damage and skin browning (Table 125).

Table 125 Rating scales for lenticel damage and skin browning severity.

Rating	Skin browning	Lenticel damage*
0	Nil	Nil
1	<1cm^2	Light spots on not more than 25% of the surface or dense pronounced spots on not more than 5% of the surface; not cracked
2	1-3 cm^2 (approx 3%)	Light spots on not more than 50% of the surface or dense pronounced spots on not more than 10% of the surface; not cracked
3	3-12 cm^2 (approx 10%)	Scattered pronounced spots on not more than 50% of the surface, or dense pronounced spots on not more than 25% of the surface; not cracked
4	12 cm^2 (approx 10%) to 25%	Dense pronounced spots on not more than 50% of the surface
5	> 25%	Dense pronounced spots on more than 50% of the surface

*The rating refers to the percentage of the overall area of skin affected by lenticel spotting. Dense = spots no more than 5mm apart. Light = 'pinprick' size. Pronounced = more than half pinhead size, dark coloured.

For Run 1, fruit were rated four and eight days after irradiation and again at full colour (when fruit had lost all green colour). For Run 2. fruit were rated every 2-4 days from the day of treatment till the end of saleable life. For Run 3, fruit were rated one day after treatment, at full colour and five days after full colour. Fruit were considered to have reached the end of saleable life if lenticel damage or skin browning severity was four or above, or six or above for both defects combined.

8.5.2.2. Effects of water

8.5.2.2.1. Fruit and treatments

B74 mango fruit were obtained from three farms in the Northern Territory on 21-22nd October 2009; Oolloo Darwin, Oolloo K1 (Katherine) and Acacia Hills (Darwin). Fruit were harvested by hand and desapped on racks without any contact with water. Treatments were applied within two hours of harvest by dipping fruit into buckets containing the following:

1. No water (Control)
2. Distilled or deionised water
3. Bore water from the same water supply used to make the harvest aid solution.

4. Harvest aid solution containing 2.5 g/L Mango Wash® (a commercial desapping detergent combining alkaline salts, phosphates, and a biodegradable surfactant). The harvest aids used a recirculating system, with the detergent fully replaced every two hours. The solution for the trial was collected about halfway through the cycle.
5. Saline solution (0.9% salt in deionised water, approximately 0.15M).

For each treatment, 36 fruit per farm were dipped for either 10, 60, or 120 seconds (12 fruit per dipping time), removed and air dried. Fruit were air freighted to Brisbane overnight and placed at 12°C at the MRS postharvest laboratories on the morning of 23rd October. On 26th October, fruit were slowly warmed to room temperature (to avoid condensation) before being irradiated at Steritech at an average dose of 410 Gy (ranging from 355-455 Gy). Fruit were transported back to MRS and ripened at 20°C (no ethylene).

8.5.2.2.2. Quality assessment

Fruit quality was assessed three days after irradiation, at full colour, and five days after full colour, as described in the "Dose response" section.

8.5.2.3. Brushing and surface coatings

8.5.2.3.1. Fruit and treatments

Fruit were obtained from Simpson Farms (Lynwood farm, Childers) on 28th January 2010 from three locations (replicates) in a slightly sloping block. The first replicate was sourced from large, dense trees in the top rows of the block, the second from smaller, more sparse trees from the lower few rows, and the third from trees halfway between replicates one and two.

Fruit were sampled either by hand and desapped on racks with no exposure to water or water-based chemicals (off tree) before being hand packed, or commercially harvested (with harvest aids using Mango Wash) and hand packed and sampled from the end of the pack line (end packline) (Table 126). Postharvest treatments were applied within 24 hours of harvest using one tray (25 fruit) per replication per treatment. Brushing treatments were applied using the brushing units of the pack line on the farm that supplied the end packline fruit. The wax coating was a commercial Carnauba-based formulation (Natural Shine TFC210) used for mangoes in Mexico, diluted 3:1 (wax:water). The coating was applied by hand to the surface of the fruit using a soft cloth.

Fruit were transported to MRS and held at 12°C until 1st February. Fruit were placed at 20°C to warm without condensation then irradiated as described in "Dose response". Average dose was 398 Gy (range of 336-451 Gy). Fruit were held overnight at Steritech in an air-conditioned room and returned to MRS the following day. The fruit were treated with 10 ppm ethylene for two days, then placed at 20°C to ripen.

Table 126 Harvesting and handling treatments applied to B74 mango fruit from south east Queensland to test the effects of brushing and waxing. Off tree = fruit harvested by hand and desapped on racks in the field. End packline = fruit collected from the end of the commercial pack line. Wax coating = Mango Carnauba wax.

Treatment	Fruit sampled	Additional treatment	Irradiation
1	Off tree	Control	Yes
2	Off tree	Brushes dry (6 brushes)	Yes
3	Off tree	Brushes wet (6 wet brushes then 6 dry brushes[1])	Yes
4	End packline	Nil	No
5	End packline	Nil	Yes
6	End packline	Wax coating	No
7	End packline	Wax coating	Yes

[1]Pack line design did not allow fruit to be removed between the wet and the dry brushing units

8.5.2.3.2. Quality assessment

Fruit quality was assessed as described in "Dose response" on one and four days after irradiation, when all fruit reached a rating of 2.5-3 for hand firmness (eating soft) and again five days later.

8.5.3. Results

8.5.3.1. Dose response

Lenticel damage on ripe fruit increased with dose from above 75-200 Gy (Figure 57; example in Plate 58), suggesting that some batches are not suitable for irradiation even at the minimum disinfestation dose of 150 Gy. However, there were significant differences between runs, and between farms (replications) within each run harvested within one day of each other in the same growing region (Table 127). This suggests growing conditions affect fruit susceptibility to lenticel damage. Maturity may also be a factor, since Run 2 fruit were just mature (about 14% DM) while Run 3 fruit were at the end of the harvest season for that growing region (average of 18.6%). Run 2 fruit were intermediate. Also, Patane fruit had higher DM (19.7%) than the other growers in Run 3, and these fruit also had the highest lenticel damage.

As seen in previous studies, off tree fruit was not affected by irradiation (Figure 57). However, fruit from field bins (commercially harvested and exposed to harvest aid water) had more lenticel damage after irradiation at about 800 Gy compared with control, but severity was about half that of fruit from the end of the pack line and irradiated at the same dose. This again confirms that picking and packing practices increase lenticel sensitivity to irradiation.

Skin browning severity increased with irradiation in all runs, regardless of harvesting treatments and irradiation dose (Table 128).

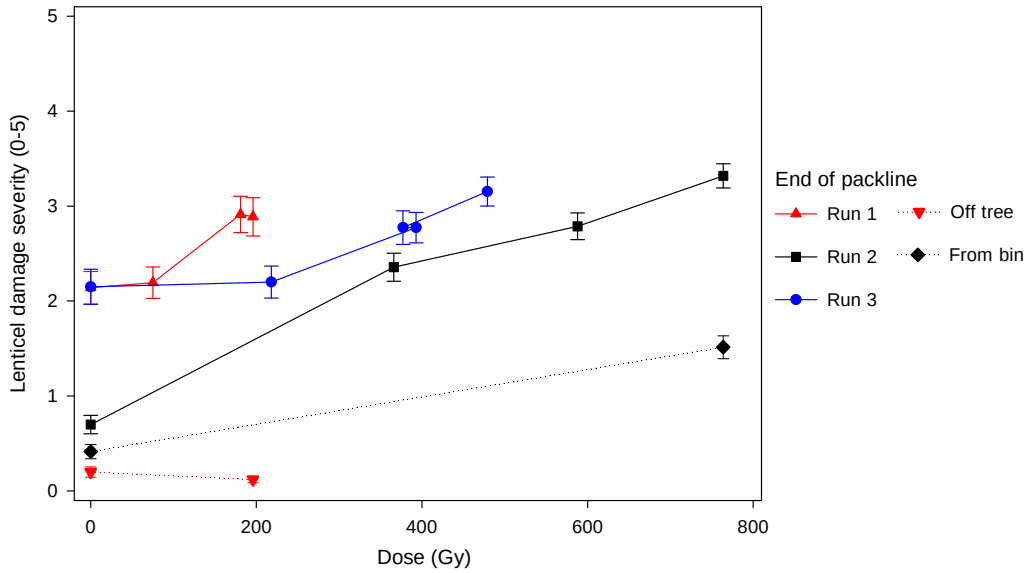


Figure 57 Severity of lenticel damage (0-5) on B74 mango fruit at full yellow skin colour after irradiation at different doses. Fruit from Run 1 were sampled from the Northern Territory in mid season, Run 2 from north Queensland early season, and Run 3, late season north Queensland. Most fruit were sampled from the end of the pack line, but several treatments were taken directly from the tree (no exposure to water after harvest; off tree) or from the field bins at the packhouse after commercial harvest using detergent solution (from bin). Vertical bars indicate standard error (n=75).

Table 127 The effect of farm (replicate) on severity (0-5) of lenticel damage in irradiated ripe B74 mango fruit. Results were averaged across all treatments within each run. Means within each run with the same letter are not significantly different at 95% confidence level.

Farm/Replicate	Lenticel damage severity (0-5)
Run 1 (NT)	
Farm 1	2.5 [a]
Farm 2	0.7 [c]
Farm 3	2 [b]
Run 2 (NQ)	
Farm 4	1.9 [a]
Farm 4 next day pick	1.5 [b]
Farm 5	2.1 [a]
Run 3 (NQ)	
Farm 5	2.4 [b]
Farm 6	3.6 [a]
Farm 7	1.9 [c]

Table 128 Severity of skin browning (0-5) in B74 mango fruit at full colour after irradiation at different doses. Off tree = fruit harvested by hand and desapped on racks in the field. End packline = fruit collected from the end of the commercial pack line. Means within each trial with the same letter are not statistically different and then at the 95% confidence level.

Fruit origin	Irradiation dose (Gy)	Skin browning severity (0-5)
Run 1		
Off tree	0	0.4 [d]
	254	1.0 [bc]
End packline	0	0.4 [d]
	75	0.7 [cd]
	181	1.4 [b]
	196	2.0 [a]
Run 2		
From bin	0	0.2 [d]
	764	1.1 [bc]
End packline	0	0.3 [d]
	373	1.5 [ab]
	593	0.9 [c]
	711	1.7 [a]
Run 3		
End packline	0	0.4 [b]
	218	1.0 [a]
	393	1.3 [a]
	378	1.0 [a]
	479	1.0 [a]

The percentage of sound fruit at full colour decreased with doses above 75 Gy for Run 1 fruit (Figure 58). Similar trends were observed in Runs 2 and 3, but the reduction in percentage of sound fruit was not as large. Lenticel damage was the main factor contributing to reduced percentage of sound fruit.

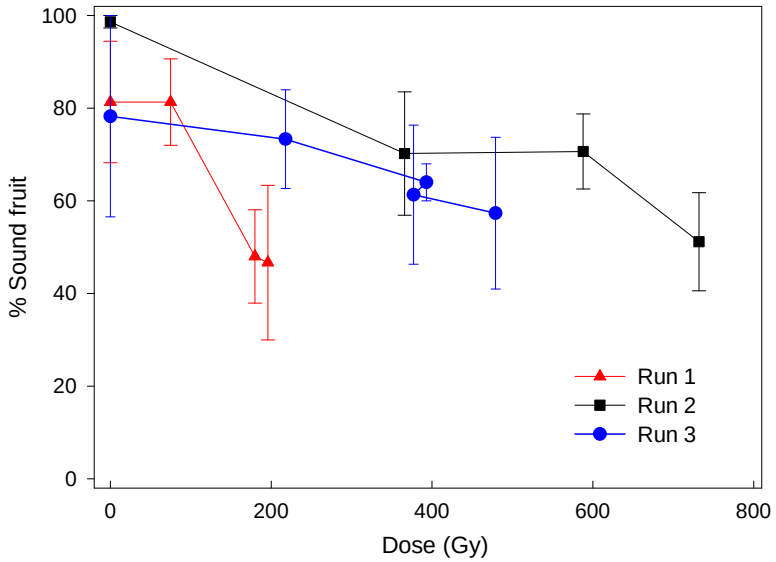


Figure 58 The percentage of sound B74 mango fruit sampled from the end of the pack line and irradiated at 0-764 Gy over three runs using fruit from different growing regions and farms. The fruit were assessed at full colour (no green colour remaining on the skin). Vertical bars indicate standard error (n=3).

In all three runs, irradiation did not affect the softening rate of the fruit, but did delay the loss of green colour (see Figure 59 as a typical example). This resulted in irradiated fruit still showing some green colour when they were at eating soft (2.5-3 hand firmness). As a result, these fruit were softer when they reached full colour compared with non-irradiated fruit.

Lenticel damage on irradiated fruit from all runs reached close to maximum severity within 1-2 days of treatment and did not consistently increase thereafter (see Figure 59 as a typical example). Lenticel damage on non-irradiated fruit was much less than on irradiated fruit and only increased after about 15 days. Therefore, irradiation caused very rapid lenticel "aging" so that damage severity usually only seen on over-ripe fruit appeared within 1-2 days of irradiation. Again, fruit sampled before packing had less lenticel damage than fruit sampled at the end of the pack line.

Irradiation significantly increased severity of skin browning after the fruit reached full colour (Figure 59).

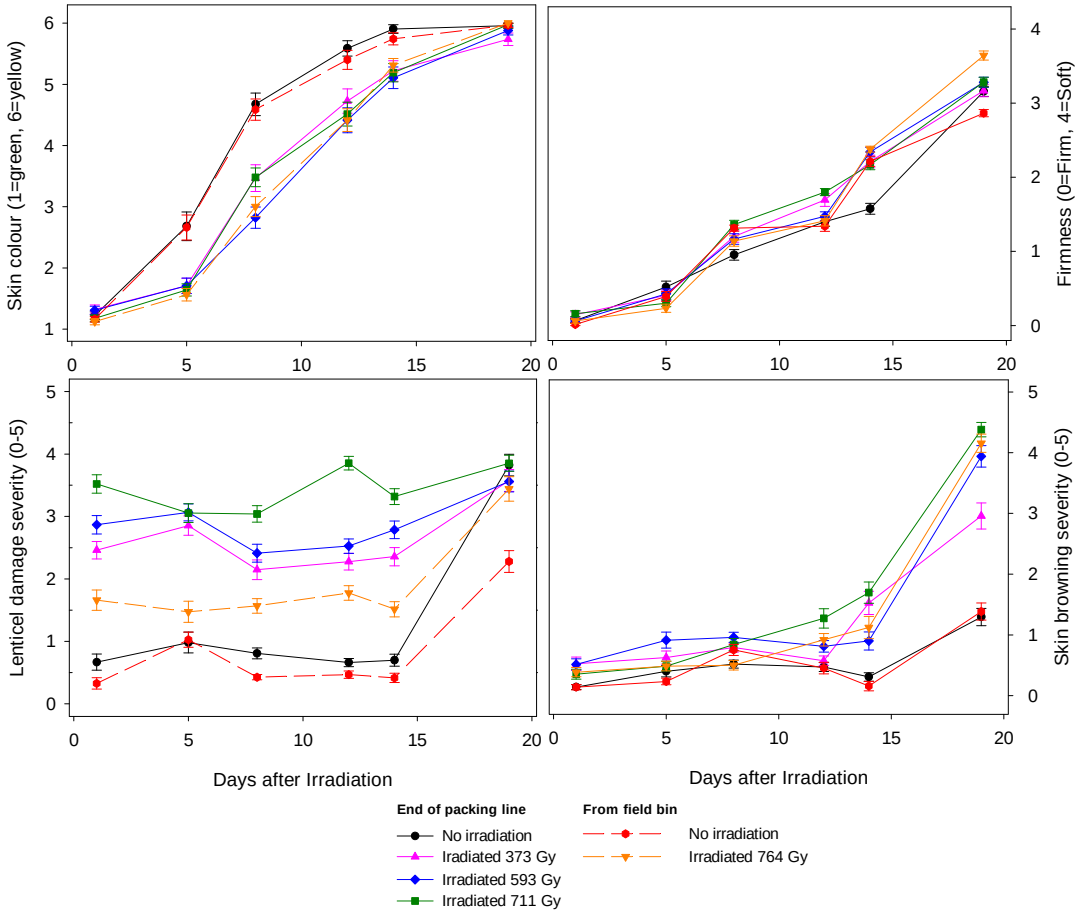


Figure 59 Skin colour, firmness, and lenticel damage and skin browning severity during fruit ripening of B74 mango fruit from run 2. Fruit were sampled either from the field bin after picking but before packing, or at the end of the pack line. Vertical bars indicate standard error (n=75).

8.5.3.2. Effects of water

Fruit exposed to deionised or distilled water for as little as 10 seconds showed more lenticel damage after irradiation compared with fruit not exposed to water (Figure 60; Plate 59). This indicates that even short exposure to relatively pure water was sufficient to increase lenticel sensitivity to irradiation. With 10 seconds exposure, there was little difference between distilled, bore, or harvest aid water, but exposure to 0.9% salt solution significantly increased sensitivity.

Longer exposure times increased the differences between the water treatments. Harvest aid solution obtained halfway through the harvest aid cycle significantly increased lenticel sensitivity following 60 and 120 second treatments, compared to bore water alone. This suggests that the detergent or contaminants that build up in the harvest aid solution during use were the main factors increasing lenticel sensitivity, rather than the bore water itself.

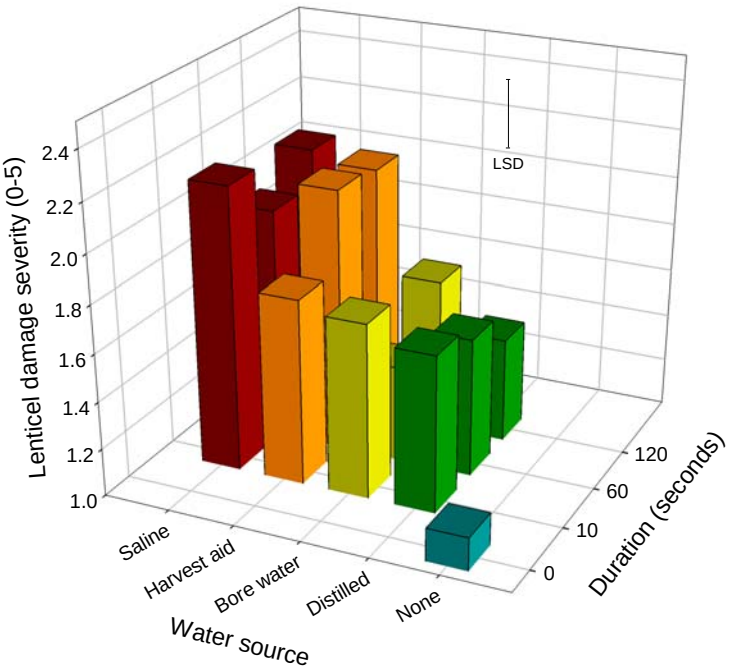


Figure 60 The severity of lenticel damage (0-5) on irradiated, ripe B74 mango fruit exposed for 0-120 seconds to either distilled water, bore water used to supply the harvest aid, harvest aid solution, or saline solution (0.9% salt). A difference between treatment bars greater than the LSD bar suggests significant treatment differences at the 95% confidence level.

Exposure for 10 seconds was sufficient to increase lenticel sensitivity, suggesting that there is little capacity to reduce lenticel sensitivity in current harvesting systems by reducing water exposure, since fruit need to be exposed to the detergent solution for at least 60 seconds to minimise sapburn/skin browning.

There were little significant differences in skin browning severity between the different water treatments and exposure times. (Table 129).

Table 129 Skin browning severity (0-5) and incidence of sound ripe B74 mango fruit (those with lenticel damage or skin browning severity below four, or below six for both defects combined) following treatment for 0-120 seconds with either no water, distilled water, bore water, harvest aid solution, or saline solution (0.9%) before irradiation at 410 Gy. Means within each skin quality attribute with different letters are significantly different at the 95% confidence level.

Treatment	Time in water (sec)			
	0	10	60	120
Skin browning severity (0-5)				
No water	0.8 ^{cd}			
Distilled		1.0 ^{cd}	0.6 ^{d}	0.9 ^{cd}
Bore		0.4 ^{d}	0.6 ^{d}	1.0 ^{bcd}
Harvest aid		0.9 ^{cd}	0.7 ^{cd}	1.7 ^{ab}
Saline		1.3 ^{abc}	1.0 ^{cd}	1.7 ^{a}

The incidence of sound fruit (those with lenticel damage or skin browning severity below four, or below six for both defects combined) was not significant (data not shown), although a trend could be observed of a general reduction with increased water contaminants (distilled to salt) and increased exposure time. On average across all treatments, 79% of the fruit were sound.

Water treatments did not affect fruit skin colour or ripening time (data not presented).

Significant differences between farms with respect to fruit responses to irradiation were again observed (Table 130).

Table 130 The effect of farm (replicate) on severity (0-5) of lenticel damage and skin browning in irradiated, ripe B74 mango fruit across all treatments. Means with the same letter are not significantly different at the 95% confidence level.

Farm/replicate	Incidence of sound fruit (%)	Severity (0-5)	
		Lenticel damage	Skin browning
Farm 1	78 [b]	1.7 [b]	1.0 [b]
Farm 2	62 [c]	2.2 [a]	1.6 [a]
Farm 3	99 [a]	1.4 [c]	0.3 [c]

8.5.3.3. Brushing and surface coatings

8.5.3.3.1. Quality during ripening

Loss of green colour (colour rating six) was delayed approximately five days in waxed/irradiated fruit taken from the end of the pack line, when compared with non-irradiated fruit and off-tree fruit (not exposed to commercial picking and packing practices) (Figure 61; Plate 60). This is also confirmed by these treatments having less yellow skin colour at eating soft (Table 131). Firmness changes were not affected by treatment (results not presented).

Brushing with six dry brushes increased lenticel damage after irradiation only slightly above no brushing, but brushing with six wet brushes then six dry brushes significantly increased lenticel damage.

Non-waxed irradiated fruit (end of pack line) showed severe lenticel spotting damage within one day of irradiation and severity did not consistently increase further as the fruit ripened (Figure 61). In contrast, the same fruit when not irradiated had significantly less severe lenticel damage, but severity increased with time particularly during late ripening. Waxing fruit after packing reduced lenticel damage after irradiation to levels similar to fruit harvested straight from the tree (no commercial picking or packing), while waxed, irradiated fruit had similar lenticel damage severity as non-waxed, non-irradiated fruit. This suggests that waxing have the potential to reduce lenticel damage to levels similar to no irradiation.

Waxing also significantly reduced skin browning, with or without irradiation (Figure 61). In most cases, skin browning increased with fruit ripening. Waxed, non-irradiated fruit developed no skin browning during ripening.

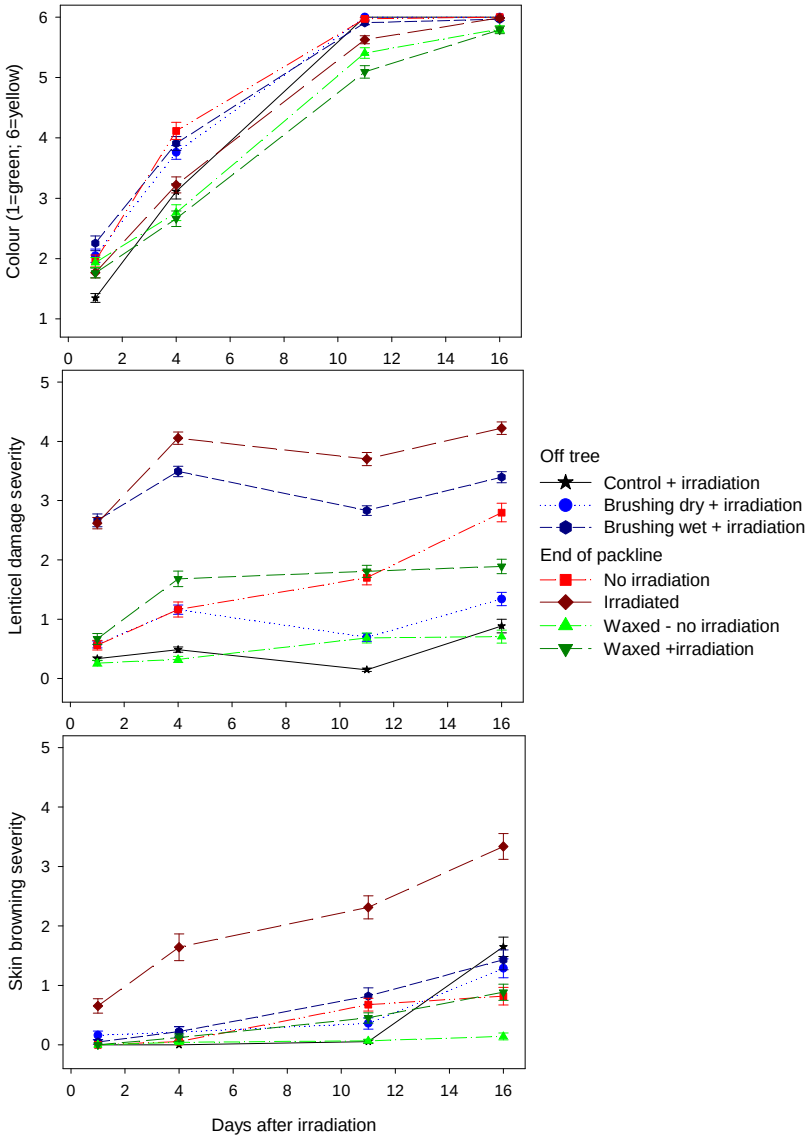


Figure 61 The development of skin colour and severity of lenticel damage and skin browning in B74 mango fruit as affected by irradiation treatment at 400Gy. (n=75)

8.5.3.3.2. Quality at eating soft

The results at eating soft mirrored those observed during ripening (Table 131). In summary:

- Brushing did not affect skin colour at ripe. However, waxing significantly reduced yellow colour at ripe, resulting in fruit having some green on the skin at eating soft. This was made worse by irradiation (Plate 60).
- Off tree, irradiated fruit had very little lenticel damage. Dry brushing increased damage slightly, while wet brushing resulted in a large increase in damage.
- Picking and packing itself (no irradiation) increased lenticel damage, while irradiation further increased lenticel damage.
- Waxing significantly reduced lenticel damage with or without irradiation. Waxing reduced lenticel damage on the irradiated fruit to levels similar to damage on non-irradiated fruit.

Similar treatment effects were observed with skin browning but at a lower severity. Skin browning severity was lowest in off tree non-irradiated fruit and waxed, end of packline fruit. End of packline irradiated fruit had the most skin browning.

Table 131 Quality of ripe (eating soft) B74 mango fruit. Fruit were either harvested by hand and desapped on racks in the field (off tree) or from the end of the commercial pack line (end packline). They were then commercially brushed with and without water, or a wax coating applied after packing. Means for each quality characteristic with the same letter are not significantly different at the 95% confidence level.

Treatment	Irradiation (Y = yes; N = no)	Skin colour (1-6)	Hand firmness (0-4)	Severity	
				Lenticel damage (0-5)	Skin browning (0-5)
Off tree (control)	Y	6.0 [a]	3.0 [ab]	0.1 [e]	0.1 [e]
Off tree + brushes dry	Y	6.0 [a]	3.0 [a]	0.7 [d]	0.4 [d]
Off tree + brushes wet	Y	5.9 [a]	2.9 [bc]	2.8 [b]	0.8 [b]
End packline	N	6.0 [a]	2.9 [cd]	1.7 [c]	0.7 [bc]
End packline	Y	5.6 [b]	2.9 [c]	3.7 [a]	2.3 [a]
End packline +wax	N	5.4 [c]	2.8 [d]	0.7 [d]	0.1 [e]
End packline +wax	Y	5.1 [d]	2.9 [cd]	1.8 [c]	0.5 [cd]

Lenticel damage and skin browning were significantly different between replicates (Table 132), suggesting fruit differences within the block.

Table 132 The effect of farm (replicate) on severity (0-5) of lenticel damage and skin browning in irradiated, ripe B74 mango fruit across all treatments. Means with the same letter are not significantly different at the 95% confidence level.

Replicate (location in block)	Lenticel damage (0-5)	Skin browning (0-5)
Top	1.4 [b]	0.2 [c]
Middle	1.8 [a]	1.1 [a]
Bottom	1.7 [a]	0.7 [b]

8.5.4. Conclusions and recommendations

The current results suggest that B74 mango quality can be reduced by irradiation at doses above 75 Gy. Similar results were obtained with Kensington Pride at doses above 300 Gy (McLauchlan *et al.* 1990). B74 fruit from some farms were more tolerant to higher doses, but minimal tolerable doses should be based on the response of the more sensitive fruit lines. Therefore, the current quarantine doses of 150 gy or more will not give sufficiently consistent results to be commercially applicable.

The significant affects of fruit origin on response to irradiation often observed in these trials suggests that understanding the production factors influencing lenticel sensitivity may help produce more tolerant fruit. Factors may include crop load, fruit size, water availability and fruit maturity, but this needs to be confirmed.

Another major factor affecting lenticel sensitivity is exposure to water during harvesting and packing, and other packing procedures including brushing. The results suggest that the lenticels are very sensitive to water exposure, and that both water itself and contaminants in the water contribute to increased sensitivity. Further investigations are required to understand why water increases sensitivity and how this can be reduced.

Browning of plant tissues normally requires oxygen, so reducing exposure to oxygen can reduce browning. Surface coatings such as waxes help reduce movement of gases (including oxygen) into the fruit, which was the likely mechanism by which the coating reduced lenticel damage in these trials. However, this treatment also reduced skin colour development to the point where fruit had green colour on the skin at eating soft. It is possible that too much coating was applied because it is difficult to apply the appropriate coating thickness using soft cloth application. If this is the case, gas movement into the fruit would have been restricted, resulting in too low oxygen concentrations and/or high carbon dioxide concentrations inside the fruit. Previous B74 research indicated that higher carbon dioxide concentrations can retard green colour loss. Further research should focus on applying thinner wax coatings to determine if lenticel damage can be reduced with no effect on skin colour loss. This should be tested using brush application as recommended by the manufacturer. If a surface coating application can be developed, the effects of these treatments on flavour will also need to be assessed.

Irradiation can also delay the loss of green colour during ripening, potentially resulting in soft, green fruit. Improved temperature and ethylene ripening recommendations may help accelerate green colour loss and result in soft, yellow fruit.

Therefore, the key recommendations are:

- Irradiation at disinfestation doses of commercially picked and packed B74 mango is not recommended at this stage given the inconsistency in fruit response. These trials identified several R&D areas to help develop a commercial protocol:
- Understanding production factors affecting lenticel sensitivity with a view to developing a predictive model, as well as identifying treatments to reduce sensitivity at harvest.
- Further understanding why water and water contaminants increase lenticel sensitivity so that strategies can be developed regarding water use after harvest.
- Further investigating the use of surface coatings to identify treatments that minimise lenticel damage after irradiation with minimum effect on fruit quality. These include applying the wax with brushes (as commercially recommended) and reducing the wax concentration to apply a thinner surface coating, and using other coatings.
- The fact that coatings can reduce lenticel damage suggests that reducing oxygen concentrations may help reduce damage expression. If this is the case, it is likely that oxidation is a key component of lenticel damage, and that antioxidants and irradiation under low oxygen conditions may reduce damage.

Off tree – no irradiation

Off tree – irradiated at 196 Gy

End packline – no irradiation

End packline – irradiated at 75 Gy

End packline – irradiated at 180 Gy

End packline – irradiated at 196 Gy

Plate 58 Skin damage of B74 mango fruit (from Run 1) 12 days after irradiation at various doses. Off tree = fruit harvested by hand, desapped on racks in the field and hand packed. End packline = fruit commercially picked and packed and collected at the end of the pack line.

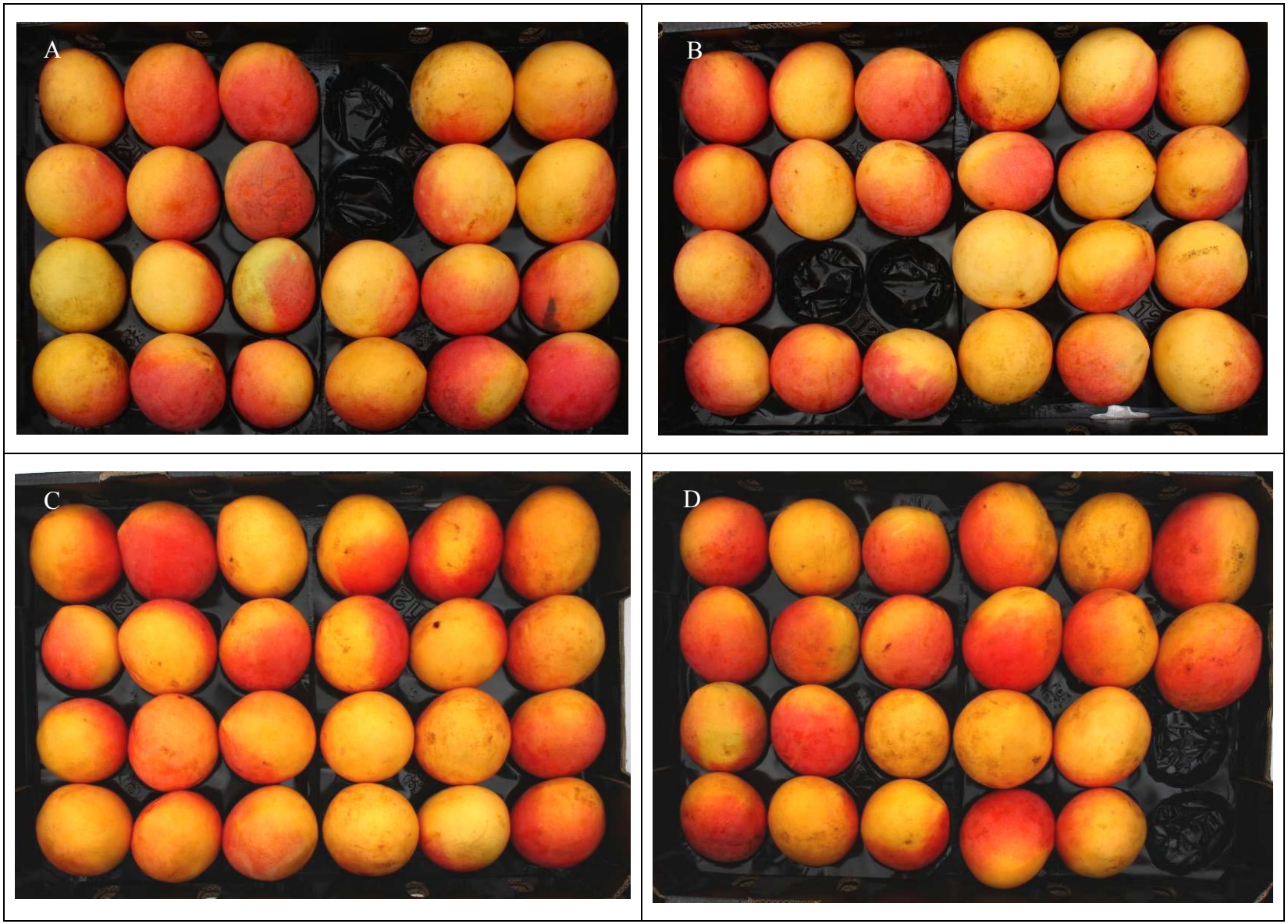


Plate 59 Skin damage on B74 mango fruit after exposure to several water types before irradiation at 410 Gy. A – distilled water; B – bore water; C – harvest aid water; D – saline solution.

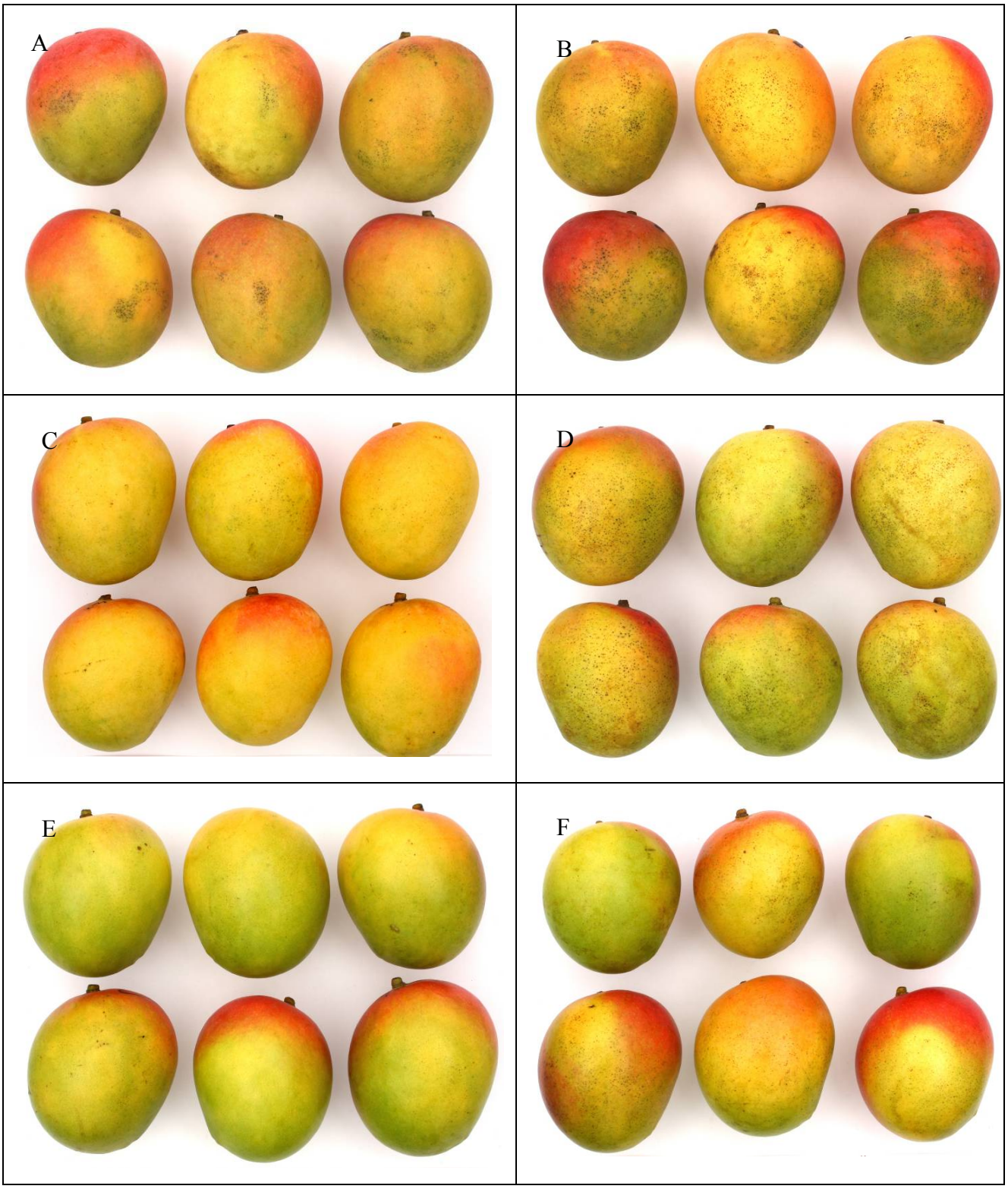


Plate 60 Skin damage on B74 mango fruit four days after various harvest and postharvest treatments. A- Off tree, brushes dry, + irradiation; B- Off tree, brushes wet, + irradiation; C- End packline, no irradiation; D- End packline, + irradiation; E- End packline, + wax coating, no irradiation; F- End packline, + wax coating, + irradiation. (Off tree = fruit harvested by hand and desapped on racks in the field. End packline = fruit that is collected from the end of the commercial pack line.)

9. Market requirements and market performance

9.1. Retail store monitoring program

Introduction

The production and sale of Calypso™ mango is relatively new in Australia since the variety was only commercialised in 1999 and it has taken some time to establish orchards and get sufficient quantities of fruit to market. The successful commercialisation of any new fruit variety requires high quality product to be available at the retail level for as long a period each year as possible. Fruit production for the supply chain has been developed through planting Calypso™ trees in environmentally different regions to ensure that a continuity of fruit is available for the length of the Australian mango season (Table 2). However, there is currently no information on the respective Calypso™ fruit quality and its interaction with transport, ripening and distribution infrastructure and their impact on retail shelf quality. A retail outturn assessment program to evaluate Calypso™ fruit quality at the point of sale was developed over the life of the project. Preliminary data was collected during the 2006/07 market season however, protocols lacked sufficient rigour to collect information that was suitable for use as diagnostic material for the other components of the supply chain. Improved protocols were developed for the 2007/08 season that produced data useful data to assist with supply chain management.

9.1.1. Materials and Methods

The retail outturn assessment program is initially based on evaluation of trays of Calypso™ fruit in Woolworths and Coles stores in the capital cities of Brisbane and Melbourne. Over time this will be expanded to other locations. Stores at each location were selected at random for assessments with a sample size in each city to give a representative result for the product. For the 2007/08 fruiting season the numbers of retailer stores sampled are listed in Table 133.

Table 133 Fruit assessment plan by month and retailer.

Month	Retailer*	
	Coles	Woolworths
November	20 stores	30 stores
December	10 stores	15 stores
January	10 stores	15 stores
February	20 stores	30 stores

*Based on 60/40 split of sales to Woolworths/Coles. Sales months of November & February being double the volume of January & December and so receiving double the assessments.

The sample population of trays to be assessed is 0.1% of the projected annual sales figure. Since the objective is to get data that relates to how consumers feel about the product "lay persons" were recruited to carry out the in-store assessments using a scoring sheet that rates external blemishes (lenticel spotting, skin browning and disease) and ripeness of the fruit. An overall appearance of the fruit on shelves was also rated. Assessments were made based on the %age of fruit in the sample tray that met the following basic criteria:

1. What %age of fruit in the tray is classed as 1st Grade fruit?
    a. No significant spotting?
    b. No large dents, bruises or skin marks?
    c. No uneven shape or other deformities?
2. What %age of fruit in the tray is considered ripe & ready to eat today?

Assessments were only carried out during the morning of each day to ensure that shelves were well-stocked with product. Only trays classed as first grade were examined. Completion assessment sheets were forwarded to the Quality Assurance team at One Harvest for collation and analysis. The sampling period was from November to February ensuring that it captures data relating to all major production areas (Table 134).

Table 134 Calypso™ mango production districts and maturity times for when fruit will be available on retail shelves.

Growing region	Sample times at retail outlets
Darwin, NT	October/November
Katherine & Mataranka, NT	November/December
Dimbulah, northern QLD	December/January
Bundaberg and Childers, southern QLD	January/February
Casino, northern NSW	February/March

9.1.2. Results

Only limited surveys were conducted because of work pressures and resignation of the key One Harvest member. However, 22 assessments were made in stores in Brisbane, Cairns and Melbourne. Of the 3180 fruit assessed, 14% had unacceptable lenticel spotting, 17% had blemishes and bruises, 12% were under-ripe and 3% had rots. Of the 15 assessments where additional comments were made, five of these stated that the fruit were over-ripe. These results confirm that lenticel spotting and skin marks, as well as over-ripe fruit are the main factors reducing the appearance of the fruit on the shelf.

Consistent feedback of poor quality fruit on the Darwin and Katherine shelves resulted in the supply chain being truncated with fruit being taken directly from local packhouses to a ripening facility in Darwin and then directly distributed to local retail outlets. This resulted in a very significant improvement in fruit quality on the retail shelf and positive comments from local consumers.

9.2. Export customer and consumer research

A confidential export customer and consumer report was prepared by One Harvest in 2008. Refer to Appendix 4 (not included in the public final report).

10. Technology transfer - Implementing better practices

The transfer of information from the Research and Development program and reports on fruit receivals and quality outturns to growers for the duration of this project was directed by the One Harvest group with the assistance of technical staff from Sunshine Horticultural Services and the Queensland Department of Primary Industries and Fisheries.

R&D Meetings

Project results were conveyed to all stakeholders each year of the project with speakers from all project collaborators taking part, i.e. Sunshine Horticultural Services, Queensland Department of Primary Industries and One Harvest. In 2007 the R&D meeting was held at the Australian Mango Grower's conference on the Gold Coast with approximately 20 people in attendance; in 2008 meetings were held in Katherine, Mareeba and Bundaberg with approximately 30 people attending across the three venues; in 2009 the meeting was held at the Australian Mango Grower's conference in Cairns with approximately 10 attendees. In addition to these end-of-season meetings a Field Day was held in Darwin in September 2008 with approximately 25 attendees. In each case results from the previous season's work were presented and discussed with the participants. The Field Day provided the opportunity to show case harvest aids and discuss Best Practice procedures immediately prior to the fruit picking season. One Harvest staff conducted a second round of annual meetings with growers immediately prior to each harvest season to discuss new protocols for consigning/reporting on fruit arrivals and quality issues. Files of the presentations of the R&D meetings are available on request.

Calypso Newsletter

For the duration of each growing season One Harvest produced an e-newsletter "Calypso™ Catchup" that was emailed to all stakeholders every 7-14 days depending on the volumes of fruit passing through the system and the occurrence of important quality issues that needed to be addressed. The newsletter also reported on weekly movements in fruit returns, any transportation issues that arose and summaries of new technology advised for implementation.

Improved Grower Communication

The success of any supply chain moving perishable products is dependent on fast and effective communication between all stakeholders. Over the duration of the project The Harvest Company (THC) developed a number of new initiatives to improve communications between its grower stakeholders and other supply chain stakeholders. A web-based system of communication was considered too slow and not accessible by all Calypso™ growers. Instead, rapid-transfer communication links were provided by email, facsimile and weekly phone conferencing. With respect to individual grower consignments of Calypso™ fruit the direct line of feedback from ripener to grower is illustrated in Figure 62. Evidence for the improvement in communication between supply chain stakeholders is given in Figure 63 through an email of appreciation from the grower to THC.

Training of ripeners

Three training workshops were provided on 1 August 2007, 17 October 2008 (both presented by Peter Hofman), and in October 2009 (presented by Leigh Barker). The workshops were aimed at improving understanding of mango fruit physiology and ripening practices. The subject areas included mango physiology, what can reduce salability, ripening practices and ripeness indicators, ripening systems, and information tools. Key staff from One Harvest, and their agents/ripeners in the major capital cities were present. Follow-up visits to some of the ripening facilities, and monitoring of room performance was undertaken. Files of the presentations of training workshops are available on request.

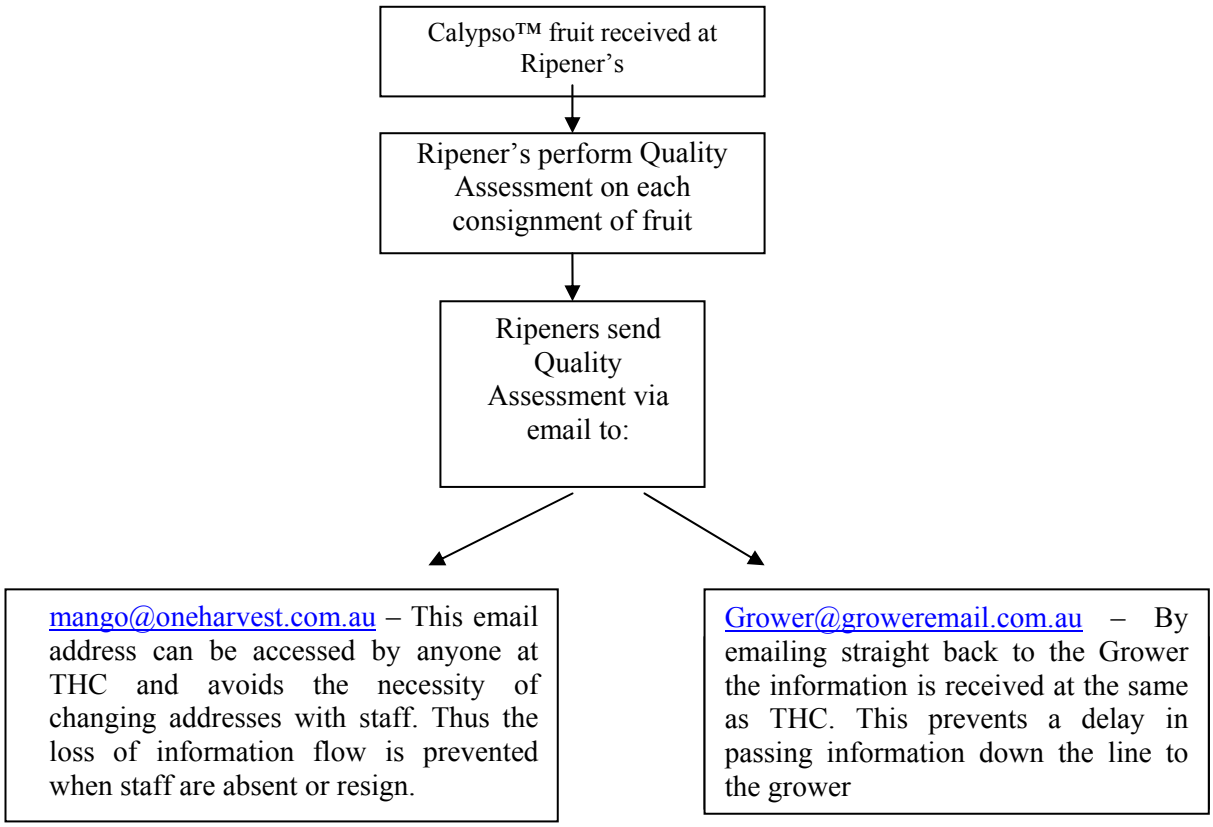


Figure 62 Flow chart detailing communication links between the fruit Ripener company, One Harvest and Calypso™ growers.

From: Sam & Kylie Collins [mailto:blushing.acres@bigpond.com]
Sent: Thursday, 3 January 2008 7:55 PM
To: Christian Capp; Sarah Faris
Cc: Robert Gray
Subject: Thank you

Hi,
I would just like to thank you both for your wonderful communication this year - you can't imagine how much difference it makes to us. We have been speaking to other growers who have also commented on the improvement.
We really do appreciate the time that you put in to a telephone call or email.
Regards,
Kylie & Sam Collins
Blushing Acres Pty Ltd
PO Box 105
Dimbulah QLD 4872
PH: 07 4093 5155
Mobile: 0400 409351
FX: 07 4093 5095
email: blushing.acres@bigpond.com

Figure 63 A Calypso™ grower expression of appreciation for improved communication links.

Training materials and guides

The first edition of the Calypso™ Best Practice Guide was published at the end of the Phase I project. The second edition will be released by end June 2010, and will include updated and new recommendations from the Phase II project.

A Calypso™ Quality Assessment Manual has been produced. It contains pictures and descriptions of the Calypso™ quality defects that occur from field and postharvest causes, provides the causes of the defects, and suggests rating scales to assess severity. It will reduce confusion among Calypso™ growers and product handlers in relation to defect names and causes, and provide consistency in ratings.

A Calypso™ skin colour chart showing fruit colour change from green to yellow during ripening has been designed and is available to One Harvest. Project staff have assisted in developing several mango handling guides and posters that are applicable to Calypso™. These are available to the whole mango industry.

The Hazard Analysis report (see Appendix 1) has been used by One Harvest to develop their standard operating practices (SOPs) for harvesting and handling Calypso™. The project staff (Whiley and Hofman) have revised the draft SOPs at the request of One Harvest. These are now being used as part of their standard commercial operations.

Publications and conference presentations

Hofman PJ, Marques JR, Taylor LM, Stubbings BA, Ledger SL, Jordan RA (2010) Skin damage to two new mango cultivars during irradiation and cold storage. *Acta Horticulturae* **In Press**.

Hofman PJ, Holmes R, Barker L (2010) 'B74 mango quality assessment manual.' (Department of Employment, Economic Development and Innovation: Brisbane).

Subedi P, Walsh K, Hofman P, Marques R (2009) Commercial adoption of a hand-held near infrared spectroscopy unit for maturity estimation in B74 mango fruit. Proceedings of the 7th Australian Mango Conference, Cairns. Oral presentation.

Hofman PJ, Marques JR, Whiley AW, Christiansen H, Walsh K, Subedi P, Leach P, Ledger, SN, Stubbings BA (2008) Horticultural R&D making a difference – The B74 Mango Experience. 'Smart Science for Innovation in Horticultural Enterprises Conference', The Australian Society of Horticultural Science, Gold Coast. Poster presentation.

Hofman PJ, Marques JR, Stubbings BA (2007). Developing maturity standards for mango – Our experience with the new cultivar B74. Proceedings of the 2007 Australasian Postharvest Conference, Terrigal, Australia. Oral presentation. Conference CD.

Hofman PJ, Ledger SN (2006) Using a supply chain approach to guide R&D. *Acta Horticulturae* **699**, 219-226.

11. Recommendations

The recommendations from this project have been well publicised to Calypso™ growers and product handlers through project activities such as:

- Pre and post-season meetings with growers
- Regular visits to growers by project members
- Information posted on the Calypso™ website
- Individual project reports at the end of each season posted on the Calypso™ website and sent to relevant growers.
- Receival assessment at the ripener for quality and maturity, with rapid feedback to growers when there are concerns. This has been particularly successful in relation to maturity standards and or lenticel spotting.
- Personal contact between growers and project staff on specific issues.
- The best practices manual produced within this project will supplement the Agrilink mango kit, and provide specific recommendations for Calypso™ developed in this project. The best practices manual will be posted on the One Harvest website and copies sent to all Calypso™ growers.

While these have been successful, additional activities would further improve implementation of recommendations. These include:

- More use of the training materials and programs produced in this project, including the ripener training workshops, the QA manual, the Hazard Analysis recommendations, and the revised CalypsoTM Best Practice manual.
- Better interaction with the ripeners and retail chains to assist in addressing the main quality issues using best practice from paddock to plate.

The following are recommendations to further develop the CalypsoTM supply chain to best service domestic and export markets. It should be noted that, while the recommendations have specific benefits for CalypsoTM, some of the experiences and principles developed during this work will have wider benefit to the whole the mango industry and other horticulture industries, and these benefits would be made publicly available for wider uptake.

- Improve the external appearance by reducing the lenticel spotting on the ripe fruit. Lenticel spotting is probably the main factor causing loss of salability of ripe fruit, and can also cause downgrading of harvested fruit. Production factors contribute to lenticel spotting but there is no indication of what these are. Lenticel spotting also increases as the fruit ripen and age, so systems to monitor and reduce the time from harvest to consumption would be beneficial.
- How long fruit can remain on the tree without quality loss. Extensive work has been done to determine when Calypso^{TM} fruit should first be harvested (maturity standards etc). The time between first harvest and when fruit deteriorate on the tree is called the harvest window. A shorter harvest window requires more investment in equipment, infrastructure and staff to harvest fruit before significant loss. A better understanding of how long fruit can remain on the tree before significant loss would identify the harvest window, and potentially help reduce investment in equipment etc.
  In addition, the major determinant of the end of harvest in the past has been fruit starting to ripen on the tree. Currently, these fruit are rejected during sorting. The harvest window could probably be extended by 3-7 days if a commercially viable fresh fruit outlet could be identified. To do this, the ability of these part-ripened fruit to withstand commercial postharvest processes need to be evaluated.

- New market access technologies, particularly irradiation. This project indicated that lenticel spotting is also the major limitation to using irradiation. A detailed study of the causes of lenticel spotting would benefit irradiation protocol development.
- Refining practices for removing field heat, and maintaining temperatures during ripening. Forced air cooling is used in both these practices. Better understanding forced air cooling requirements will increase efficiency and energy use when cooling fruit after harvest, and a better understanding of how to maintain temperatures during ripening will result in more even and consistent ripening.
- Improving flavour. The Phase 1 and II projects developed maturity standards based primarily on flavour assessment, sugars (Brix) and acidity. Aroma compounds are also significant contributors to flavour, but were not included in these studies because previous research indicated that fruit maturity at harvest is a major determinant of flavour through sugars concentration (Brix). There is little understanding on the relative contributions to flavour from aroma compounds, sugars and acidity, and whether flavour can be improved by manipulating aroma compounds in a mango cultivar.
- Delivering fruit directly from the farm to the retailer. Several days delay in ripening can have financial implications for early season fruit when the demand and price is high. Ripening fruit in transit may reduce delivery times by up to four days, but there are risks associated with poor temperature control in the trucks as the fruit ripen. Good temperature monitoring of commercial consignments will identify whether current rate freight technology can maintain the 18-20°C temperatures required for acceptable ripening.
- Develop a more efficient system for regular monitoring of fruit from harvest to sale from the retail shelf, and outturn quality on export markets. This should include an efficient, web-based reporting system for rapid access by all stakeholders.
- Regular assessment of fruit at retail level in Australia, and the training of retail produce staff in handling of Calypso™. This may help address some of the issues identified during the retail surveys in this project, particularly time in the system. A commitment from the retail chains would be essential in this process.

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13. Appendix 1

Development of best practice pre- and postharvest protocols for production of 'B74' mango: phase II

(HAL MG06005)

Review of harvesting to retail procedures to reduce quality loss in B74 mango

2008/9

Peter Hofman and Scott Ledger

Queensland Primary Industries and Fisheries

14. Appendix 2

Queensland **the Smart State**

Vapour heat treatment against Queensland fruit fly, *Bactrocera tryoni* (Froggatt) in B74 mangoes.

Sub-project of "Development of best practice pre and postharvest protocols for production of 'B74' mango: phase II"

Horticulture Australia Ltd MG06005.

Leach *et al*
Horticulture and Forestry Science
Queensland Department of Primary Industries and Fisheries

HAL Know-how for Horticulture™ one harvest Queensland Government Department of Primary Industries and Fisheries

15. Appendix 3

Understanding skin and lenticel damage in mangoes with special reference to irradiation and under skin browning

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16. Appendix 4

One Harvest

Export customer and consumer research

The key objectives of exports this year were to:

a. Develop and execute a successful program into an overseas retailer (Singapore was chosen)
b. Understand the market acceptability of airfreight Calypso™ in selected target markets (Canada, Hong Kong, Middle East, New Zealand and China were chosen)
c. Successful commercial sea freight container (Singapore was chosen)
d. Continue market access into Japan and US for future markets

1. Program into an overseas retailer: Singapore by air and sea

We believe our future with export will be in a programmed approach to overseas retailers, either through importers (where this makes sense) or direct. Singapore was an ideal choice to test this approach for several reasons:

- Whilst Singapore has only a few million consumers, their purchasing power and love of consumerism makes them a relatively strong market for targeted products – especially in comparison to their much larger neighbours (in terms of population and land size) Malaysia and Indonesia.
- It is a relatively accessible market with air freight readily available and competitively priced at around $5.75/tray. Sea freight is also a viable option due to sufficiently short voyage times.

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