Horticulture Innovation Australia

Final Report

Quality standards, refinement and testing

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The Department of Agriculture and Fisheries (DAF)

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Content

Summary

The 3 key aspects influencing consumers purchasing habits are visual appearance, eating quality or flavour and price. Eating quality of ripened fruit is correlated to % dry matter in fruit at harvest, which in turn is linked to the maturity (as opposed to 'ripeness') of the fruit. This project focused on a number of strategies to improve the reliability of getting fruit harvested at the right maturity and hence fruit at maximum flavour to consumers. The first strategy provided mango growers and retailers with awareness of and access to the new technology of F750 NIR spectrometers (NIRS) to help estimate dry matter as a measure of fruit maturity. This raised the awareness of the opportunity to monitor dry matter along the supply chain, within the context of affordability and ease of use of the new technology. This technology was then used in the market end of the supply chain. The second strategy validated the estimation of dry matter content of ripening fruit across a number of Australian mango varieties. NIR-DM models were developed using hard green fruit and were used in the prediction of DM in ripening fruit for the varieties Kensington Pride, Calypso, R2E2, Honey Gold and Keitt. Predictions were repeatable for early stages of ripening but were less so for fully ripened fruit. These models were programmed into F750 NIR spectrometers as calibrations to estimate dry matter content of fruit in wholesale markets. The mango industry through the Australian Mango Industry Association offered transparency and encouraged peer to peer compliance by publishing the weekly results of estimated fruit dry matter content measured at wholesale markets and retail distribution centres. In the 2016/17 season many growers and retailers trialled the use of the NIR spectrometers, building confidence in the predictability of mango flavour, which then underpinned successful retailer promotional campaigns in the 2016/17 mango season.

Keywords

mango, maturity, dry matter, near infra red, ripeness

Introduction

Definitions of fruit **maturity** and **ripening:** A fruit is ***physiologically mature*** when it reaches a stage at which it will continue development even if detached from the plant. A fruit reaches ***harvest maturity*** after physiological maturity. For climacteric fruit like mango, this is the stage of development when the fruit will ripen to acceptable consumer quality. Harvest maturity can be estimated by characteristics like fruit % dry matter (% DM) or flesh colour, because these change as the fruit reaches harvest maturity. A fruit reaches ***consumer maturity*** when it is ready to eat. For mango this is after ripening. ***Fruit ripening*** involves change in skin and flesh colour, decrease in firmness, conversion of starch to sugars and an increase in volatiles (which contribute to the ripe fruit smell and characteristic flavour), and can occur on or off the tree once the fruit is physiologically mature.

Previous consumer research clearly shows that visual quality is one of the key aspects consumers consider when purchasing mangoes. Once purchased, to gain repeat purchase, consumers need to be satisfied with eating quality. This project aims to improve the industry capacity to meet consumer expectations for appearance and flavour of mangoes. With this confidence, retailers can then embark on more effective promotional campaigns to manage supply and work with industry promotional initiatives to increase demand.

At the commencement of this project, some Australian retailers had more than 40 quality specifications focused on appearance of mangoes due to a combination of geographically spread production districts, a range of mango varieties, the perceived need to have a different quality standard in contrast to other retailers, varying qualities targeting different markets and demographics, and due to a legacy of past relationships between a revolving door of retailer staff's relationships with individuals in the industry. Multiple specifications led to confusion and inefficiencies in Australian mango supply chains.

In this project, it was important to clearly distinguish fruit maturity and fruit ripeness. Some fruits including mangoes are usually picked mature but unripe so that they can withstand handling systems when shipped long distances (Kader, 1999). Maturity at harvest is important as it determines both shelf life and final fruit quality when ripe. Fruit maturity in mangoes can be judged by a number of factors including the use of heat sums, dry matter (DM) of the flesh, internal flesh colour and fruit shape. Mango fruit ripening processes include changes in skin colour, reducing firmness, and the breakdown of starches in the fruit to sugars. Therefore the previous quality assessment practice of assessing Brix of ripening fruit created uncertainty, as the Brix level increases as fruit ripens, so the Brix level was impacted by the ripeness stage at which the fruit was assessed.

Mango fruit have a limited window of time when they can be picked. Picked too early, fruit will not be at the correct minimum maturity level. If they are left on the tree too long, their shelf life decreases, and they will become more susceptible to pests and diseases and will ripen on the tree, and lose value. Therefore timing the harvest window for each block/orchard is critical to the commercial viability of every grower.

Mango sales can be an important driver for retail produce sales and whole of store sales. Fortunately, over mature fruit rarely ends up at the retail store as over-mature fruit have often started the ripening process and become too soft to withstand the transport from farm to retail. Immaturity on the other hand is a far more likely risk to which the mango industry is exposed, like many other fruit industries. The lure of high prices for early fruit can sometimes lead to immature fruit being sent to retailers, resulting in inferior flavour for the consumer. Heavy supplies of immature fruit can slow sales and reduce prices, shifting shopper preferences to other fruits. Until recently it was typical to find mangoes of differing maturity and ripeness in the same consignment and in the same box further disappointing consumers and retailers.

For the past few years, the Australian mango industry has been concerned about the issue of inconsistent fruit maturity and had promoted retailers to include Brix as an indicator of fruit maturity. However, Brix as a measure was seldom used because it required destructive and time consuming sampling of fruit. Brix was also a difficult measure to interpret, because as the fruit ripened the Brix would increase substantially. Even if retailers measured Brix, they couldn’t be sure whether the fruit was immature or simply hadn’t ripened enough when the sample was taken.

The use of DM as a maturity measure shared similar challenges of cost and convenience, but at least remained relatively stable from the time a mango was picked until the time it was eaten. DM is an index of both starch and sugar within the fruit. As the fruit ripens, starch converts to sugar, such that overall the DM does not change as the soluble sugar content (Brix) level rises (Subedi et al., 2010). There has been a long standing recommendation on a minimum DM of 14% for fruit at harvest. Henriod (2015) established that minimum DM specifications for several varieties of mango, i.e. DM levels associated with Brix levels in ripened fruit that were acceptable to consumers. Thus a DM specification was developed associated with the minimum acceptable brix in ripened fruit.

Fruit DM has traditionally been assessed using a slow and destructive oven drying technique that took 24-48 h. As a result, DM levels were rarely checked. Near infrared (NIR) spectroscopy was first applied to commercial fruit grading in Australia (by Colour Vision Systems) some 20 years ago (under an IP licence from Central Queensland University; CQU). Handheld, portable NIR technology has been steadily developing, as seen in a release in September 2015 of a dedicated fruit quality spectrometer by Felix Instruments. However the technology had been used in assessment of hard green fruit (where starch is the main storage carbohydrate) or in some cases fully ripened fruit (where the starch has been converted to sugars). Further work was required to demonstrate use in ripening fruit, which have varying starch-sugar ratios. This would allow NIR use at all major stages in the supply chain.

Methodology

The methodology of this project is presented in three sections.

1. Provision of technical and training resources targeting the retail sector

a) Review of quality standards and assessment procedures

Due to the competition in the retail sector, the proliferation of production areas, varieties produced and high staff turnover in the retail sector, significant differences had developed in quality standards used by different domestic retail organisations. The project team supported AMIA to benchmark existing visual and flavour aspects of national quality standards and then sought consensus to a rationalised (two grades instead of three) set of quality standards agreed to by retailers and packing sheds nationally.

b) Provision of training to retailer quality teams in quality assessment:

The retail sector in Australia has considerable turnover in staff, and to ensure that this sector was efficient, effective and informed as possible to play a productive role on mango supply chains, quality control staff, category managers and distribution centre staff in each of the major retail companies were targeted for training in mango quality. The provision of training to the retail sector dovetailed with planned industry promotional activities engaging the retail sector. The training was offered to staff in Coles, Woolworths, Harris Farm Markets, Metcash/IGA, Costco and Aldi in Brisbane, Sydney and Melbourne. The training was flexible to the interests of the retail staff and included:

- Where are mangoes produced and what varieties are grown when
- Why does the timing of the mango season change slightly every year
- Enhanced understanding of physiological changes in fruit as they ripen and especially in climacteric fruit such as mango
- Correct identification of major and minor defects and the likely causes
- Consumer acceptance and non-acceptance of defects
- When do defects typically appear on or in fruit
- The role of temperature management in fruit storage and ripening
- Fruit maturity and ripeness assessment at the retailer distribution centres (DCs).

Aside from the training sessions, resources were also made available to the retail staff including:

- Video training on mango quality assessment
- Use of available industry Quality Assessment Manuals, mango handling guides and electronic versions of imagery for in-house material development.

2. NIR estimation of maturity and ripeness

Calibration models were developed for the Felix Instruments F750 NIR spectrometer to estimate fruit maturity (DM) in hard green fruit and in ripening fruit (fruit in which the starch:sugar ratio is changing).

The ripening fruit project proposed to estimate dry matter and Brix in at least two mango cultivars from 1-2 growing regions and across ripening stages, with testing on independent populations of fruit. It was proposed that the first year of work would entail taking a population of 100 fruit from a given variety/location, treating with ethylene, ripening, measuring NIRS absorbance, then assessing 20 fruit at each of 5 times during ripening for destructive measurement of Dry Matter, Brix, penetrometer-firmness and flesh colour. Work was to occur at Central Queensland University in Rockhampton in January 2016, to develop models across ripening fruit of several cultivars. Further work was proposed in year 2 with fruit sampled from two Brisbane distribution centres (DCs) over 1-2 weeks, followed by demonstration of the technology to AMIA and DC staff.

In practice, significantly more work was undertaken. Work was undertaken in Brisbane, rather than Rockhampton, to expedite the process, with work extended to include more varieties (4 in each year), fruit populations (4 per variety in each year) and instruments (7 F750 units in year 2, and consideration of SunForest (SunForest, Jeju Island, Korea) and Scio (Consumer Physics, Jerusalem, Israel} units in comparison to F750). Proof of concept was achieved in year 1, with demonstration to AMIA and Woolworths' staff at end of season. In year 2, the robustness of the technology was demonstrated while at the same time the greater project team rolled out the technology to markets in Brisbane, Sydney and Melbourne. This required extra resources from CQU to support the extra researcher time, travel costs and hire of Brisbane laboratory facilities from DAF.

3. Raising awareness and capacity of using new NIR technology with mango growers and packers in key growing areas.

The project subcontracted the Australian Mango Industry Association (AMIA) to employ a full-time Supply Development Manager (SDM) during the 2015/16 mango season to work with growers in the major production districts to raise awareness and capacity of using portable NIR devices, including:

- Raising awareness of industry agreed quality appearance standard for each grade
- Raising awareness of industry agreed quality (maturity) standards
- Raising awareness of the variety of approaches to assist in the decision to pick process
- Testing the maturity of mangoes using an NIR device in grower orchards to provide growers with advice on fruit maturity in each key region
- Ensuring NIR tools being used by growers were correctly calibrated (by CQU) and users received the appropriate training in their use
- Collecting fruit samples from a range of varieties and production districts for NIR calibration by CQU.

Outputs

The outputs of this project are presented in three sections.

1. Provision of technical and training resources targeting the retail sector

- Consensus to a grade 1 and grade 2 mango quality standard to be used by all retailers. A copy of the grade standard and the associated posters were outputs under a separately funded project and as such are not presented in this report.
- Consensus to the use of NIR to estimate DM as a maturity standard as a more reliable indicator of ripe fruit flavour compared with destructive Brix of ripening fruit.
- In 2015/16, training was delivered to all national Metcash/IGA category managers in Sydney, replacing the three training sessions planned in Brisbane, Sydney and Melbourne for this retailer.
- In 2016/17, 14 workshops were delivered to staff in Coles, Woolworths, Aldi, Costco, Metcash/IGA and Harris Farm Markets in Sydney, Melbourne and Brisbane and via videoconferencing to staff in Hobart, Adelaide and Perth

Table 1: Attendees at mango quality workshops delivered in the 2016/17 season.

State	Coles	Woolworths	Aldi	Costco	IGA Metcash	Harris Farm Markets
NSW	8	11*	6	6	7	2
Vic	3	16**	3	-	-	-
Qld	5	3	6	-	10	-

* From two separate workshops

** Included live videoconferencing link to Woolworths staff in Tasmania, South Australia and Western Australia.

2. NIR estimation of DM

The output from this work was (a) calibration of F750 units used by the AMIA Supply Development Manager and the NT Farmers Association for estimation of DM in hard green fruit, and (b) development of a calibration for estimation of the DM in ripening fruit, subsequently used by AMIA market assessments and in retail demonstrations.

In 2015/16 one NIRS instrument was calibrated for DM assessment of four varieties (KP, R2E2, Calypso and Keitt), each involving four populations of fruit (from different growing conditions, n=100) with spectra collected over the course of fruit ripening. This was repeated in 2016/17, but extended across 7 F750 instruments. The handheld NIR spectrometers were calibrated using partial least squares regression models. Models developed on hard green fruit were not suitable with ripening fruit, but models developed by including ripening fruit data proved reliable across all stages of ripening except over-ripened fruit (e.g. Figure 1; see Appendix 1 for detail). It is postulated that the light scattering properties of over-ripened fruit were different to those of non-ripe to ripe fruit.

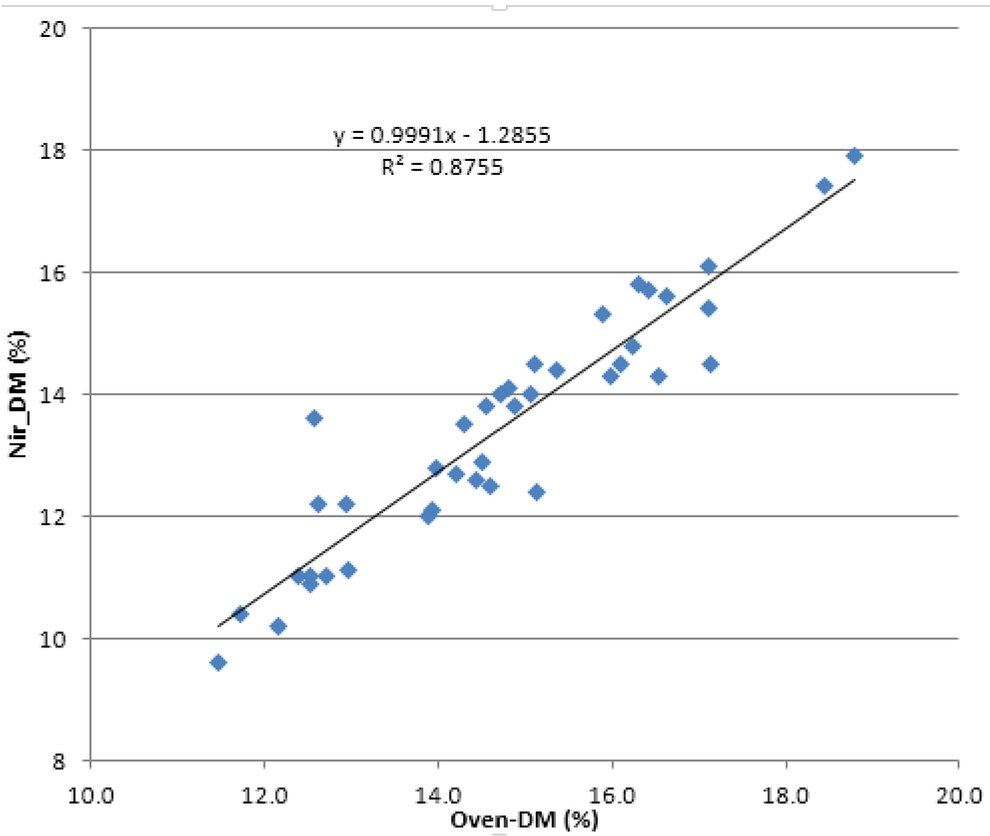

Figure 1. The relationship between actual DM as determined by the oven method, and the DM estimated by NIR using a prediction model which includes fruit of a range of ripening stages.

Typical performance in assessment of DM of independent populations (i.e. fruit not used in calibration) was R^2=0.8-0.95 and RMSEP = 0.5-0.9 %DM (against oven DM), based on use of individual variety and unit calibrations. NIR-DM models were developed using hard green fruit and were used in the prediction of DM in ripening fruit for the varieties Kensington Pride, Calypso, R2E2, Honey Gold and Keitt. Predictions were repeatable for early stages of ripening but were less so for fully ripened fruit. Cross variety calibration demonstrated promise for some varieties (Appendix 3). Further work on cross variety and instrument calibration is recommended.

Use of the SunForest unit was discounted due to its geometry being unsuited to mango (optical front must 'fit' the fruit). The Scio unit was unable to operate in high ambient light conditions.

There was a significant initiative to keep the industry informed of the progress with NIRS and calibration through the industry magazine Mango Matters. Examples published during the project included:

- "AMIA's Gingin Field Day" Mango Matters V23, March 2016, p24-25,
- "Dry Matter matters" Mango Matters V23, March 2016, p20-21,
- "Fruit maturity: developing an application to assist with the decision to pick" Mango Matters V27 March 2017, p20-22, and
- "Factors that influence dry matter" Mango Matters V27 March 2017, p23-25.

3. **Raising awareness and capacity of using new NIR technology with mango growers and packers in key growing areas**

The SDM worked with growers in each region as the harvest progressed through northern Australia. Prior to the commencement of harvest in each region, the Supply Development Manager visited grower's orchards. Visits were conducted in Darwin, Katherine, Burdekin, Mareeba and the Gingin region of Western Australia. During each visit a sample of mangoes in the orchard was tested with the F-750 Produce quality meter to estimate fruit DM and therefore whether the crop was ready to pick. In doing so, the SDM provided awareness to growers of quality standards (DM and brix) through individual meetings and presentations at grower workshops.

The SDM also worked with grower groups (e.g. Northern Territory Vietnamese Horticultural Association) on issues relating to fruit maturity and other issues impacting on quality (e.g. resin canal discolouration). The SDM provided information to new and existing growers on industry best practices. Growers often had questions on quality issues and the SDM either addressed these questions during the orchard visits or information was sought from the appropriate specialist and the information provided to the grower.

During the 2015/16 season, the SDM visited over 100 growers in the Northern Territory, Queensland and Western Australian. The Supply Development Manager often visited growers multiple times during the weeks prior to harvest to assist them with assessment of fruit maturity and the decision to pick process. Each region was visited in the lead up to harvest and through the early part of each regions harvest period. The number of growers/orchards visited during the lead up to each regions harvest period are reported in the table below:

Region	No of growers/ orchards	Proportion of regional production managed by the growers that were visited
Darwin, NT	29	80%
Katherine, NT	11	95%
Bowen/Burdekin/Townsville, Qld	23	70%
Mareeba/Dimbulah, Qld	40	86%
Central and South East Qld	26	95%
Gingin, Southern WA*	11	?

* Plus a grower field day and visits to several farms in the Gingin, southern Western Australian region

The SDM also worked with CQU and Northern Territory Department of Primary Industries and Fisheries (NTDPI&F) staff to ensure that the F-750 Produce Quality Meters owned by or available to industry were calibrated for key Australian varieties and provided information on use to growers and orchard managers who were utilising these meters in their decision to pick process.

During the season the SDM also visited the wholesale markets on several occasions and communicated with wholesalers and their representatives regarding fruit maturity, ripening processes and quality. The visits were undertaken in Sydney twice in early and late December, in Melbourne in late December, and in Brisbane, fortnightly from October to February 2016. Activities included discussions on quality and quality standards, discussions on crop flow, informal monitoring of incidence of quality issues (e.g. resin canal discolouration), and gathering information on issues arising in the market to inform growers during farm visits. Information on quality issues was communicated to growers either directly through discussions, and/or indirectly through industry publications. The SDM also significantly contributed to the development of industry quality specifications mentioned in the article “AMIA’s Gingin Field Day” in Mango Matters, March 2016, p24-25.

Outcomes

The outcomes of this project relate to consumer expectations in relation to appearance and flavour.

1. **Increased capacity in the retail sector**

   Interest in the mango quality workshop leading into the mango season was strong in 2016/17 and was fuelled by four factors;

   - There was a new agreed mango quality standard common across all retailers.
   - Previous effort has been focused on grower suppliers, wholesalers and to a lesser extent ripeners. The retail sector had not been heavily targeted in the past, despite the reasonably high turnover of retail staff who are often unfamiliar with particular requirements of the seasonal mango supply.
   - The 2017 start to the mango season had been 1-2 months later than 2015/16 due to late flowering. Retailers were eager to get supplies of fruit, and they were keen to understand why and how to more objectively assess whether fruit were mature enough to ensure good customer eating quality,
   - 2015/16 represented the first year with new NIRS technology to objectively assess maturity of ripening fruit to improve consumer eating experience. 2016/17 was the first year that AMIA initiated a market survey process in the Brisbane, Sydney and Melbourne wholesale markets, collecting data on DM levels as assessed using NIRS. The data from this separately funded initiative was openly shared through the industry communication initiatives and domestic mango supply chains. These included the weekly “My Mango” newsletters, monthly “The Slice” newsletters and quarterly “Mango Matters” magazine. Due to the separately funded nature of this work neither the sampling regime nor the data from this initiative is presented in this report.

   Balancing the need for accountability with the fact that most workshops had only on average 6 participants, the workshop facilitators sought mainly verbal feedback from the small workshop groups. Concerned that some workshop participants may have been shy about expressing any level of dissatisfaction in the workshop, confidential written feedback forms where introduced for a sample of 3 of the 14 workshops. The evaluation (see Appendix 1) verified the strong support for the workshops and the intent by 94% of participants to use the information and knowledge in their current role in their business. Most businesses participating in the workshops also noted that some staff were unable to attend due to other work or leave commitments, so numbers could have been higher. Generally the workshop participants had a range of experience from 6 months to 30 years working with mangoes.

   The workshops provided:

   - An excellent opportunity to clearly separate the concepts of maturity and ripeness with retailers, and to better understand challenges that their ripeners face.
   - Encouragement for ongoing adoption of the industry quality standards and the implementation of best practices through the supply chain to meet/exceed mango quality standards.
   - More consistent identification of mango quality problems by retail sector staff.
   - More consistent use of industry-agreed terminology to describe quality defects and concerns. Photos of some workshops are presented in appendix 2.
   - Improved communication with the mango supply chain to help remedy some quality issues during the season and others before next season.
   - Potential for less variability in fruit quality presented to the retail sector and hence greater sharing of

improved supply chain efficiency with supply chain members.

Critical success factors for future streamlining and function of domestic supply chains include:

- Finding out what skills the retail sector have in assessing and communicating concerns with mango fruit quality and tailoring the training to retail sector needs.
- Delivery of the agreed number of training sessions.
- Providing back up resources to trainees such as a training video (for use by retail staff who attend the training, then with their staff in the company) and mango quality assessment manuals (from AMIA).

Evidence for the uptake of these ideas and technology was seen at the Australian Mango Conference 2017 event, attended by Woolworths, Coles, Aldi and Harris Farm (Figure 2).

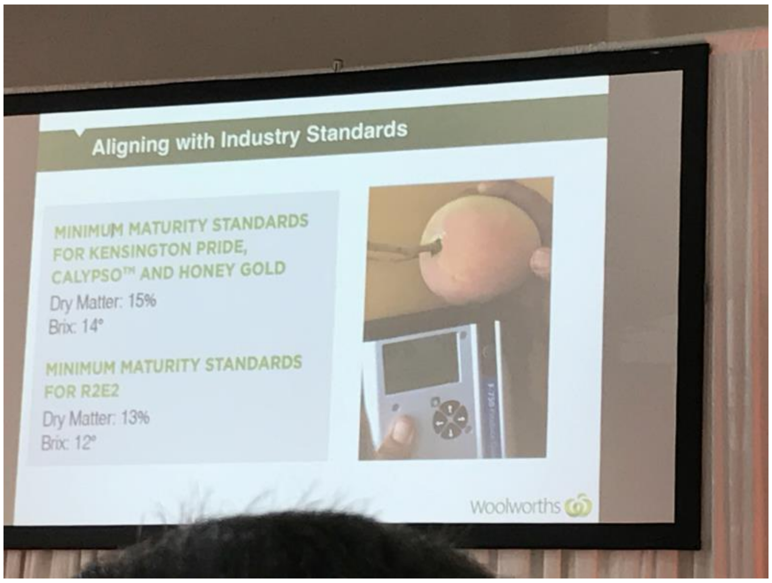

Figure 2. Slide from Woolworths' presentation to growers at the Australian Mango Conference 2017, explaining use of NIR-DM.

2. Raised awareness and capacity in using new NIR technology

Over the 2015/16 and 2016/17 seasons, the development and implementation of NIR technology in the mango industry was recognised by growers and other supply chain stakeholders as a significant positive change for the industry. Assessing dry matter by traditional sampling and drying techniques has been seen by many as too time consuming and was not widely adopted. Growers who did not use dry matter as a tool in the decision to pick process would use other methods, including flesh colour and fruit shape. The introduction of NIR technology will provide growers with more objective and accurate information to assist them with their decision to pick, contributing to improved and more consistent quality mangoes reaching consumers.

A good demonstration of industry satisfaction, particularly as it translated to a contribution to price received, was in a recent article on ABC media (http://www.abc.net.au/news/rural/2017-05-03/mango-innovation-leads-to-success-growers/8492972). The following is an excerpt from that article:

More than 200 growers attending the 11th Australian Mango Industry Conference in Bowen have been told it *was no coincidence the retail value of the mango crop increased by 40 per cent in the past three years — more than double the overall fruit category.*

Australian Mango Industry Association marketing manager Treena Welch said exceeding consumer expectations hinged on the ability of growers to adopt innovation to improve the eating experience.

Ms Welch said the real game changer had been the rollout of Near Infra-Red (NIR) technology, which enables growers to pinpoint the precise optimum harvest window for their crop, regardless of location or variety.

Based on consumer research, the minimum benchmarks for dry matter content of fruit is set at 15 per cent for Kensington Pride (Bowen), Honey Gold and Calypso varieties, while R2E2 required 13 per cent.

"NIR, that's the one that has changed the industry forever more," Ms Welch said.

"They literally shoot the fruit on the tree and instantaneously they get a reading, a near infrared reading, of what the dry matter of that fruit is.

"And then they make the decision to pick or to leave the fruit on the tree a bit longer until it reaches that minimum dry matter level.

The added bonus for the mango growers and packers is the ability to make more objective decision about the harvesting or seasonal window to the associated ability to plan access to seasonal labour requirements.

Evaluation and discussion

1. Provision of a technical and training resource

The retail quality control and buying staff were very receptive to the mango quality training and suggested that it would be of great value every year or two as a refresher as they approach the mango season. Recognising the repeated resources required, information was also loaded to YouTube (https://www.youtube.com/watch?v=eD7PR4PHViw) for repeated and timely access by participants.

The simplification of grade standards across retailers would have had efficiency gains for growers and pack sheds but data on this was not recorded as part of this project.

2. Raising awareness and availability of NIR technology with mango growers and packers in key growing areas

While the awareness and acceptance developed over the two seasons was important, the most critical success factor in this project was acceptance by the industry and transparency that came from a key grower in the Northern Territory who led a push to develop industry social license through publication of the results of weekly dry matter monitoring in a newsletter mailed weekly to all of the industry and supply chain.

3. The use of the handheld NIRS along the supply chain

The benefit of NIRS monitoring of maturity at multiple points in the supply chain is dependent on risk of immature fruit entering the supply chain in the first place, and cost of surveillance using NIRS technology. The industry approach of early (pre-harvest) testing of fruit in orchard and assessment of fruit received at market in combination with complete transparency regarding the results reduces the risk of immature fruit in the markets.

It should be noted that the minimum recommended DM is set in context of the ripened fruit Brix and flavour, not fruit harvest maturity per se. The DM associated with harvest maturity (i.e. attainment of greater than the minimum DM plus factors such as fruit shape and size, and flesh colour) should be established for a given cultivar/growing condition. Slabby fruit shape can result in reduced value. There were some criticisms from growers about the SDM saying fruit were ready to harvest based on the minimum DM specification only.

4. Handheld NIRs use for farm and market evaluations

Consideration needs to be given to future application of the technology. Larger growers, particularly those with orchards spread across geographic districts, may purchase and maintain their own NIR unit. Smaller growers would benefit from visits, as conducted by AMIA and NTDPIF in the past two years. However, these visits need to be timely, and during the weeks before harvest. Regional consultants may play a service delivery (consultancy) role.

Also, while the DM models have proven relatively robust across time, the NIR method can only estimate DM, and regular quality checking is required. Without this in place there is the risk of inaccurate predictions.

5. Overall Project

This project focused on a number of strategies to bring about a practice change in the mango industry. This sustained change can be discussed in the context of the 5 doors model of behaviour change (Robinson 2011). For some time there had been a desire (door 1) by some mango supply chains to improve the consistency or predictability of mango eating quality in retail stores and to address the risk of immature fruit. This is a common problem in many fruit industries.

However the lack of an agreed measure and suitable technology was a significant barrier. The availability of a portable NIRS systems to estimate fruit maturity via DM in ripening fruit was a technological trigger providing an enabling context (door 2). This project focused on building mango supply chain members' self-efficacy by lowering the perceived risks of action (door 3) through raising awareness of the opportunity, demonstrating the affordability and ease of use of the new technology, confirming industry support, and building confidence in the technology through scientific validation (robust calibrations for the main varieties). However, most importantly the industry (AMIA) created a buzz (door 4) that offered transparency and ensured peer to peer compliance by publishing the weekly results of the supply chain monitoring. This allowed the industry to invite interest from all sectors of the supply chains (door 5) and resulted in industry and retail support for broader testing of the technology (change). This change then led to a rise in supply chain confidence in the predictability of the technology, which then underpinned successful promotional campaigns in the 2016/17 mango season.

Les Robinson (2011) goes on to mention that 'satisfaction with the trial' is a key step after the trialling, supporting the value of an industry review of the entire process.

Recommendations

To maintain the change that the industry has secured in terms of improved maturity of harvested fruit, an appropriate strategy should be put in place to maintain that commitment through the supply chain. The key elements are likely to include:

- Felix Instruments to fund work to facilitate model transfer across instruments as a priority concern, to improve practical deployment of the technology.
- AMIA to propose a 2017/18 and 2018/19 season strategy specifying the level and locations of supply chain surveillance of fruit maturity relative to the risk of immature fruit entering supply chains.
- Supply chain surveillance should ensure sampling of at least 25 fruit per consignment/lot, given typical attribute variation.
- AMIA to identify an agreed strategy between the industry, packing sheds and retailers that confirms who bears what costs in surveillance of maturity, with consideration of fruit maturity service delivery models that allow for shared costs (e.g. between smaller growers) and timely orchard assessment ahead of harvest. A recommendation of quality control of NIR DM assessment (equipment calibration) is also required.
- AMIA to set a key performance indicator regarding the maximum level (e.g. no more than 10%) of monitoring results below the variety DM standard before the strategy is reviewed.
- AMIA to continue to openly publish dry matter surveillance results in regular communication products.
- AMIA to promote the development of a levy funded project prior to the 2018/19 season to update training resources (reflecting changes in mango varietal mix in that season) as a YouTube video and industry promotion of the resource, targeting staff at mango packing sheds, ripeners and retail quality staff.
- AMIA to review the refined retail quality standards with industry stakeholders after three years.

Scientific refereed publications

None to report to date.

A manuscript of DM model robustness in ripening fruit will be prepared and submitted to Postharvest Biology and Technology.

Industry publications and news

Australian Mango Industry Association newsletters

- "AMIA's Gingin Field Day" Mango Matters V23, March 2016, p24-25,
- "Dry Matter matters" Mango Matters V23, March 2016, p20-21,
- "Fruit maturity: developing an application to assist with the decision to pick" Mango Matters V27 March 2017, p20-22, and
- "Factors that influence dry matter" Mango Matters V27 March 2017, p23-25.

"Retailer Presentation" by Woolworths at 11th Australian Mango Conference 2017.

"In Field Tools for Estimation of Fruit Quality and Quantity", presentation by Kerry Walsh, Phul Subedi, Nicholas Anderson, Zhenglin Wang and Anand Koirala (CQU) at 11th Australian Mango Conference 2017.

"Aus growers attribute mango crop's 40% rise in value to innovation", Source: http://www.freshplaza.com/article/174953/Aus-growers-attribute-mango-crops-40-procent-rise-in-value-to-innovation

"Mango innovation leads to success growers" article on ABC at http://www.abc.net.au/news/rural/2017-05-03/mango-innovation-leads-to-success-growers/8492972)

Intellectual property/commercialisation

No commercial IP generated

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Appendices

Appendix 1. Evaluation of the mango quality workshops

(Based on written feedback from a sample of 19 participants in 3 workshops)

Interest

Treena Welch (AMIA) and Noel Ainsworth (QDAF) were asked to deliver 14 mango quality workshops in Oct/Nov 2016 reaching 86 retail distribution centre quality control and buyer staff nationally in Coles, Woolworths, Aldi, Costco, IGA Metcash and Harris Farm Markets.

Reactions

What I liked;

- In-depth explanation on what really matters. Very informative.
- Videos about mango / presentation. Instrument for testing Brix.
- Very informative.
- It was very informative from quality perspective.
- Information was informative and short. Didn't drag on.
- The correct explanation of maturity in the mango process from start to sale, thankyou.
- Effective nature of dry matter content at the time of plucking to the quality of the fruit in the marketplace.
- Informative, interesting, increased knowledge
- Information re dry matter
- New machine for dry matter. Plan AMIA and where we are concentrating regions we obtain fruit from.
- Interesting and some new information provided.
- Informative presentation on industry innovation
- Understanding what gives us best eating experience
- Understanding the picking and QC process. The explanation of defects.
- Practical demonstration about dry matter measurement
- The information very detailed
- Care and logistics of shipping
- The education and understanding of its growth pattern

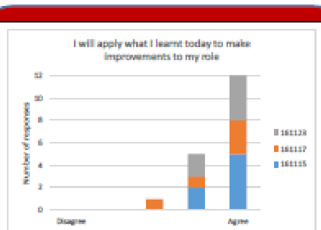
Suggestions to improve;

- Cannot flaw the workshop. Fantastic.
- It should be more elaborative, bit thorough on subjects
- Updates time to time
- Great as it is.
- Add consumer information
- n/a very happy with the workshop
- More demonstrations with actual fruit showing different maturity level, spots etc.

Comment;

- This was of great value and relayed more information which we can use in practice.
- Very informative for information to project assessments in the future for the better.
- More industries need to apply these type of workshops
- Great delivery
- New technology seems great for industry
- Updates on the QA process/information to educate staff
- Nutritionals

Aspirations



..... 94% of participants could apply improvements to their role as a result of the workshop

Appendix 2: Photos from the mango quality workshops

1. Coles (Qld)
2. Metcash (Qld)
3. Aldi (Vic)

4. Felix F-750 Produce Quality Meter in use at a workshop

Appendix 3. Use of short-wave near infrared spectroscopy for dry matter assessment of ripening fruit

Kerry B. Walsh and Phul. P. Subedi
Central Queensland University

Introduction

Mango fruit accumulate starch during maturation on tree, which is converted to soluble sugars during ripening (be that on or off the tree) (Fig. 1). Dry matter content (DM) of the fruit is determined by constituents of relatively fixed levels (e.g. cellulose, protein) and by constituents that vary in level such as the starch and sugar content of the fruit. Thus DM is an effective indicator of the sum of starch and sugars in the fruit.

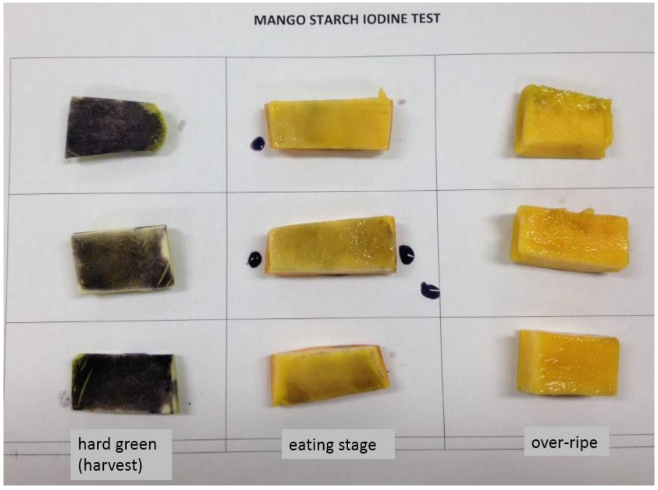


Figure 1. Cores of mango fruit flesh stained (blue-black) for starch using I-KI. Tissue from fruit at hard green (left panel), eating stage (middle panel) and over-ripe (right panel) fruit, of three separate fruit for each ripeness stage.

For example, for fully ripened fruit, in which all starch has converted to sugars, DM is well correlated to sugar content (Brix) (Fig. 2). Moreover, the DM content of fruit is generally stable from harvest until fully ripe (Fig. 3). While there is some loss of DM expected due to respiration during ripening, this is apparently offset by an increase in DM due to loss of water during ripening/storage (Fig. 3). Thus, as established by Subedi and Walsh (2007), fruit DM at harvest (the sum of starch and sugar in the fruit) is an index of the soluble sugar content (SSC or Brix) of fully ripened fruit (Fig. 3).

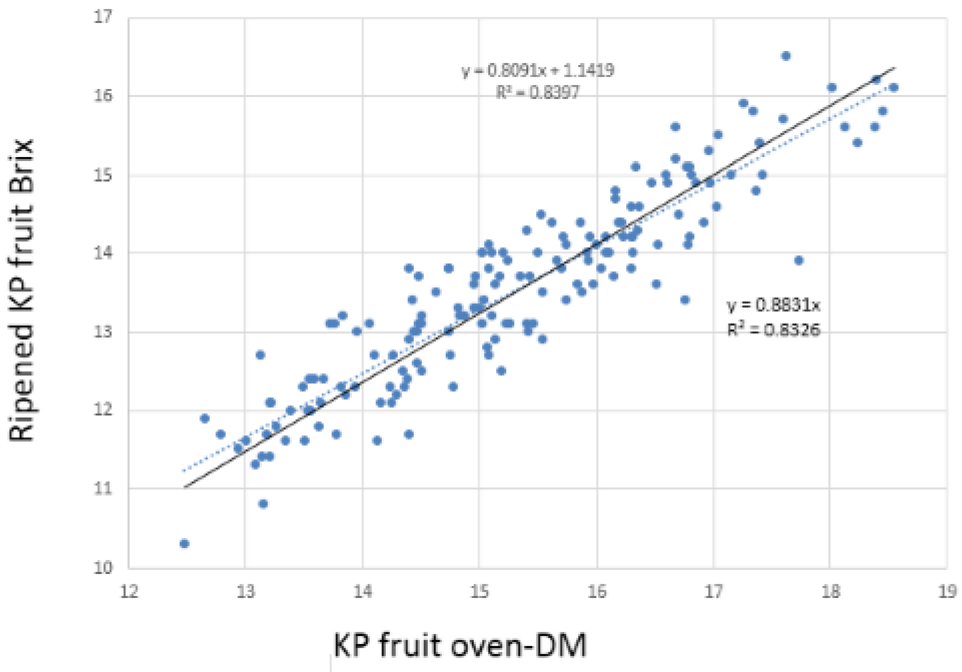


Figure 2. Fruit DM and Brix of full ripened KP fruit.

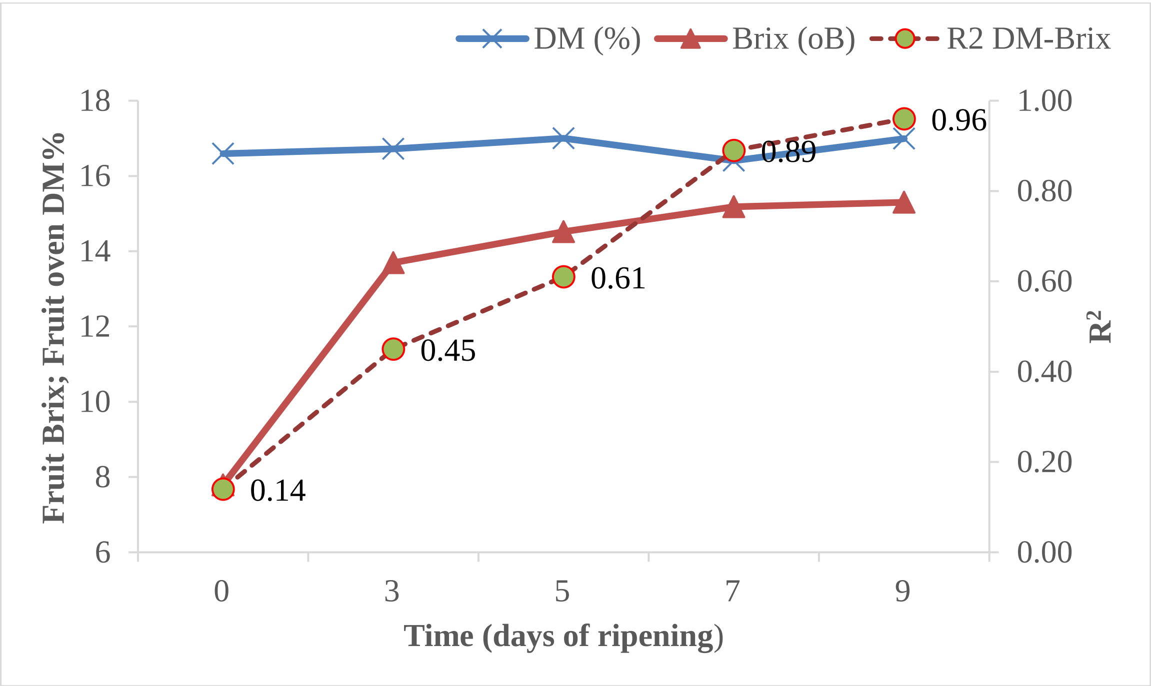


Figure 3. Change in R2E2 fruit DM and Brix as fruit ripen, and the correlation coefficient of determination between these two attributes.

The correlation between DM and Brix is weaker for over-ripened fruit (data not shown), presumably as the senescence of the fruit involves solubilisation of a range of other components within the fruit tissues.

Thus DM at harvest is a useful indicator of Brix of ripened fruit, which is expected to correlate with eating quality. The relationship between DM and eating quality has been demonstrated by Henroid et al. (2015) and also work done by Carlos Crisoto (pers. comm.) of UC Davis for the US Mango Importers Association, leading to recommended specifications on DM level by variety.

Handheld shortwave near infrared spectrometry has been utilised for non-invasive assessment of hard green fruit (e.g. Subedi et al., 2007), allowing measurement of fruit DM on tree (e.g. Fig. 4). Such data is currently being used by farm mangers to better schedule harvest timing, to achieve the recommended DM specification.

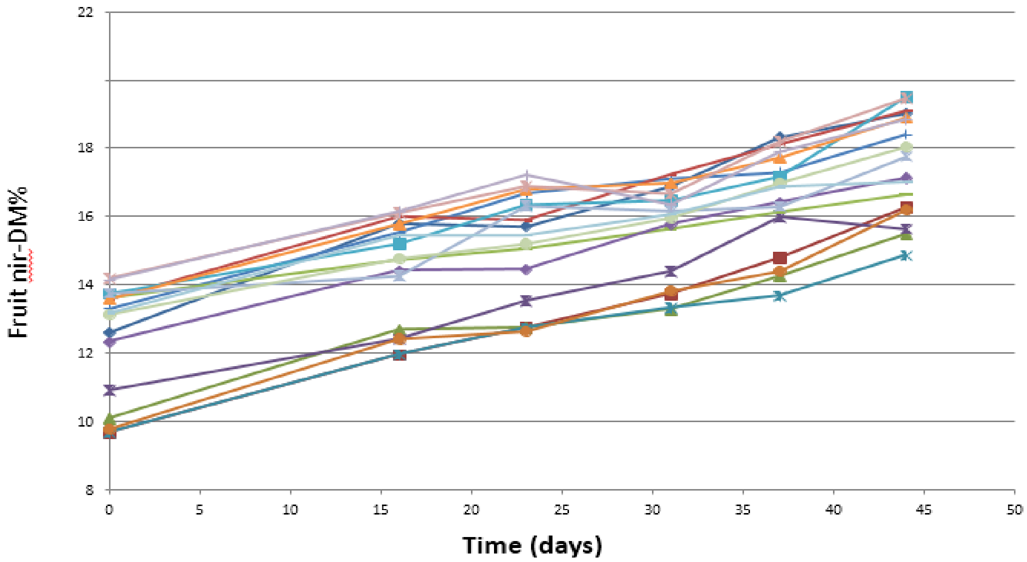


Figure 4. Time course of NIR-DM assessed of individual (Calypso) fruit on tree. The average rate of increase (0.73% DM/week) can be used to forward estimate when a desired DM specification will be reached.

However, while DM is now 'routinely' assessed of hard green fruit, the robustness of the NIR method for assessment of DM in ripening fruit required confirmation, given changes in the chemical matrix and physical (e.g. light scattering) properties that occur in ripening fruit. For example, Subedi and Walsh (2011) have reported on a lack of accuracy in prediction of Brix in ripening fruit, but results for Brix in ripened fruit and DM in ripening fruit were promising. It is postulated that the NIR method is suited to the robust determination of intact fruit DM (i.e. the inverse of water content, water being easily 'seen' by NIR), as opposed to the discrimination of soluble sugar from starch as required for estimation of Brix in ripening fruit.

Exercises with ripening fruit

The F750 Fruit Quality spectrometer (Felix Instruments, Camas, WA, USA) was used. This is a handheld vis-swnir (350-1100 nm) photodiode array instrument, operating with an interactance ('shadow probe') optical geometry. Nipals partial least squares regression models were developed using second derivative (Savitsky Golay, 8 point window) of absorbance data over the wavelength range 725 – 975 nm. PLSR calibration models were based on 9 or less PLS factors, based on cross validation using groups of 20 samples.

Oven DM% was assessed of 30 mm diameter, 20 mm deep cores of flesh (skin removed) at the point of spectra acquisition, with dehydration in a domestic dehydrator unit at 65°C.

Fruit was supplied from several growing districts (as supplied by AMIA), with mean and SD of DM varying by cultivar (Table 1).

Table 1. Population statistics (sample number and oven DM mean and standard deviation, SD) as used in PLSR exercises, and PLSR cross validation statistics (R^2, RMSECV, #f - number of factors in model) for each variety.

Variety	n	Mean	SD	R^2cv	RMSECV	#f
KP	200	13.85	1.52	0.88	0.53	8
Calypso	200	16.58	1.10	0.75	0.55	8
R2E2	200	14.10	1.48	0.90	0.46	9
H Gold	200	19.18	2.95	0.93	0.76	7
Keitt	200	15.63	1.48	0.83	0.60	8

A NIR-DM model developed using hard green fruit was used in prediction of DM in ripening fruit. Predictions were repeatable for early stages of ripening but were less so for fully ripened fruit (Fig. 5, Table 2).

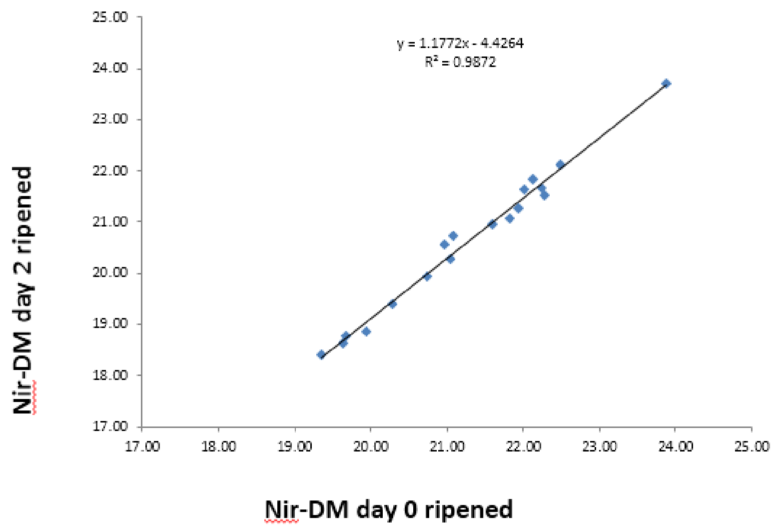


Figure 5. Comparison of NIR-DM values estimated of the same fruit (n = 20) at hard green (day 0) and after 2 days of ripening.

Table 2. Correlation coefficient of determination (R^2) for NIR-DM of the same fruit estimated at hard green stage (day 0) and after different ripening periods (as indexed by fruit Brix). A PLSR model based on hard green fruit was used in estimation of fruit at different stages of ripening.

Ripening time (days)	Fruit Brix	R^2
0		0.99
2	9.9	0.99
4	12.0	0.96
8	16.4	0.87
10	17.5	0.79
12	17.5	0.68

For each variety, a PLSR model was built using spectra and oven DM values of fruit at different stages of ripening, RMSECV values of less than 0.8%DM were achieved for all models (Table 1). To confirm model robustness across ripening stages, PLSR models were then developed with inclusion of fruit at different stages of ripening. These models were then used in prediction of DM in ripening fruit, of fruit not included in the calibration set (i.e. independent populations). Results were acceptable (i.e. R_p^2=0.8, RMSEP <0.8%DM) (e.g. Fig. 6). This example is typical of results achieved with each variety.

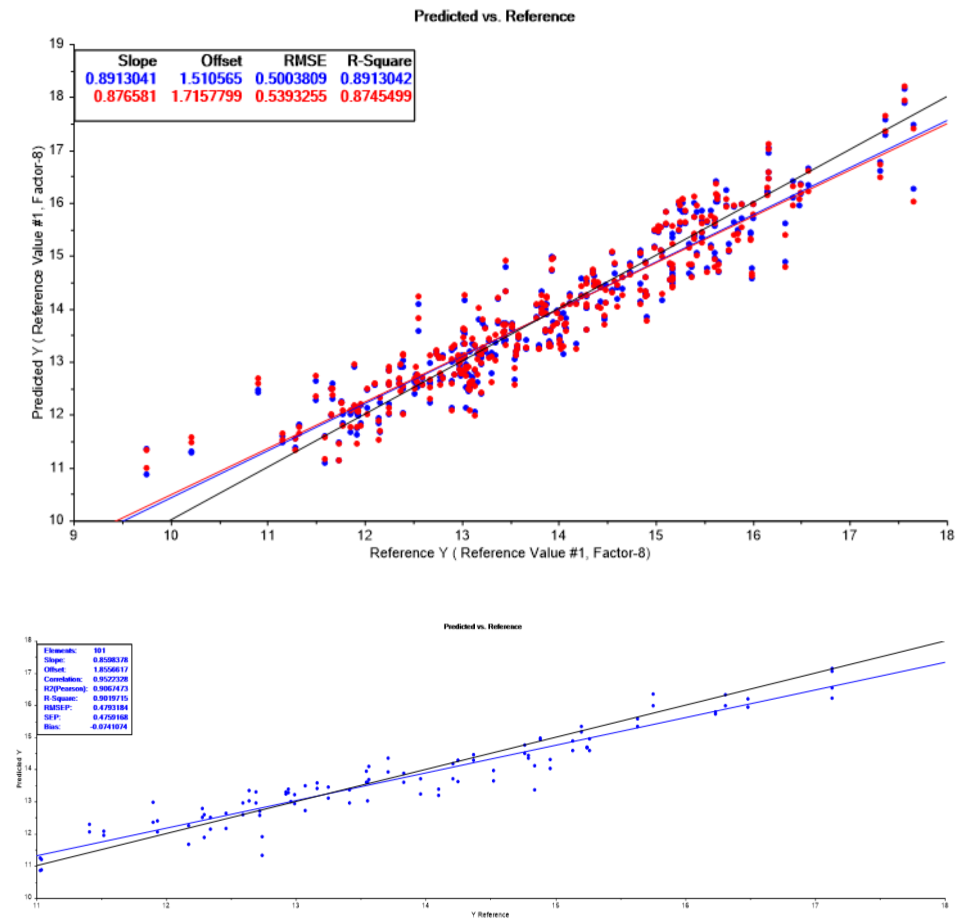


Figure 6. (A, top panel) Example of scatter plot and calibration model statistics for a model developed using (KP) fruit at a range of ripening stages (fruit at hard green stage (day 0) and at 1, 2 and 4 days of ripening) (n=332, SD = 1.52, mean = 13.9). (B, bottom panel) Example of prediction of DM in ripening (KP) fruit, of fruit not included in the calibration set (3 day ripened fruit) (R^2p=0.91, SEP=0.47, bias = -0.07%DM). In top panel, blue points are calibration results, red are cross

validation results.

Scatter plots for the PLSR models of two example models follow, as used in market assessments/ demonstration work (Fig. 7). This data is from one F750 instrument, but is indicative of that obtained with another 6 units. A typical RMSECV of < 0.6%DM was achieved.

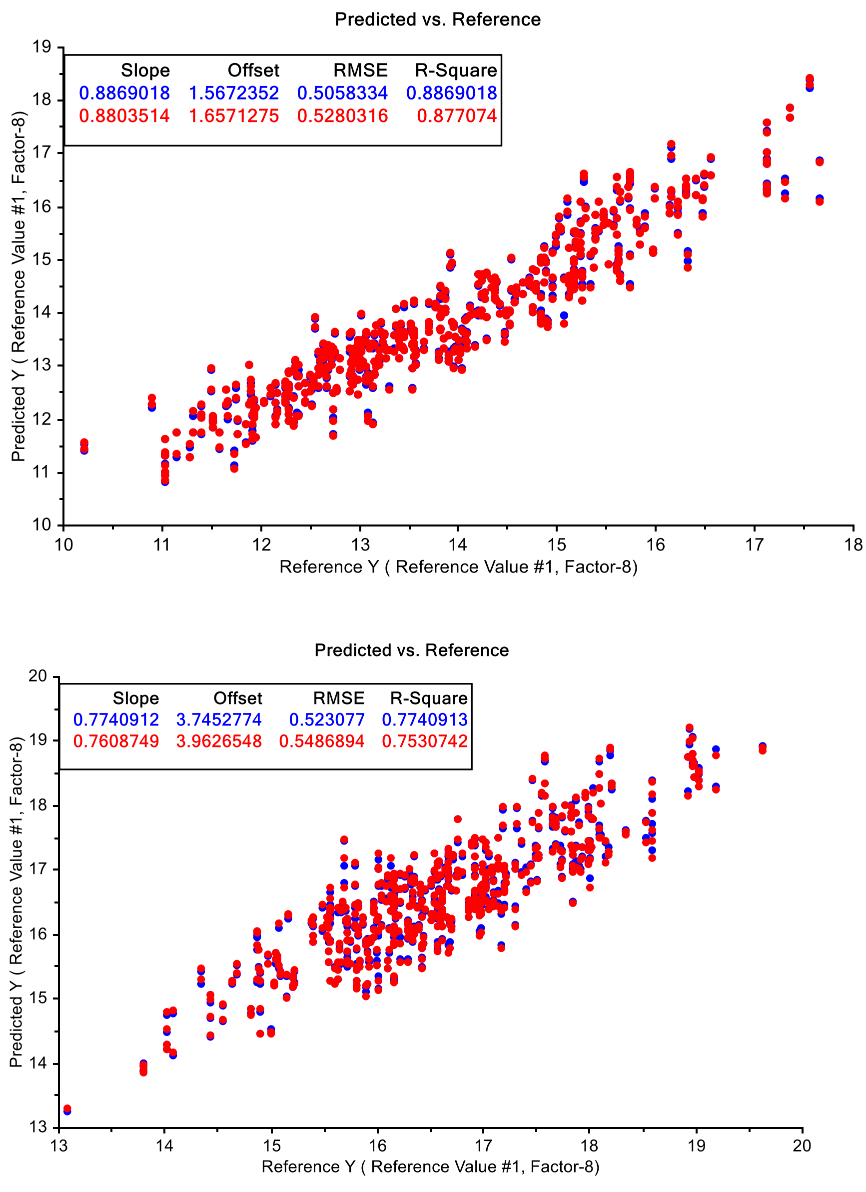


Figure 7. Calibration (cross validation) results for DM estimation in fruit at different stages of ripening (n = 200 in each panel). Top panel : KP; second panel : Calypso

The use of a PLSR model developed for one variety was trialled for estimation of DM of fruit of other varieties (Fig. 8). The results were not acceptable for commercial use, with Keitt prediction being particularly problematic (bias of -1.23 %DM).

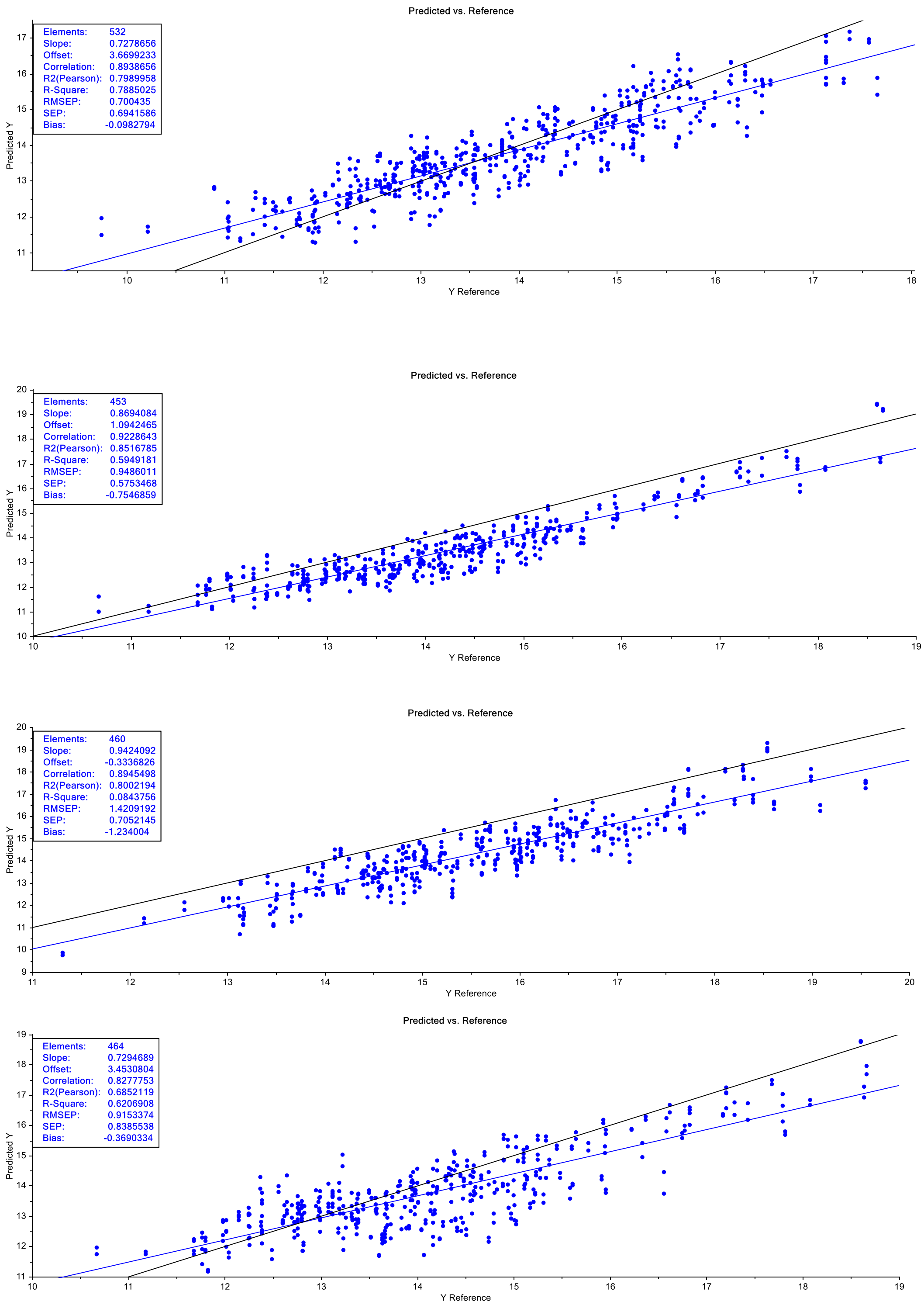


Figure 8. Prediction results for a PLSR model based on Calypso fruit at different stages of ripening, used in prediction of fruit of other varieties at different stages of ripening (n = 200 each).

(a) top panel: KP fruit: R^2 = 0.80, SEP = 0.7%DM bias = -0.1%DM
(b) HG fruit: R^2 = 0.92, SEP = 0.6%DM bias = -0.8%DM
(c) Keitt fruit: R^2 = 0.80, SEP = 0.7%DM, bias = -1.2%DM
(d) R2E2 fruit: R^2 = 0.69, SEP = 0.8%DM bias = -0.4%DM

A preliminary consideration of the use of combined variety ('global') calibrations was undertaken. Calibration statistics for a model containing data of all varieties were acceptable (R^2>0.9, RMSE = 0.7 %DM) (Fig. 9). Model coefficients were similar to that of a single variety model, with use of 7 PLS factors (Fig. 10), indicative that the global model was not over-fitted to the data.

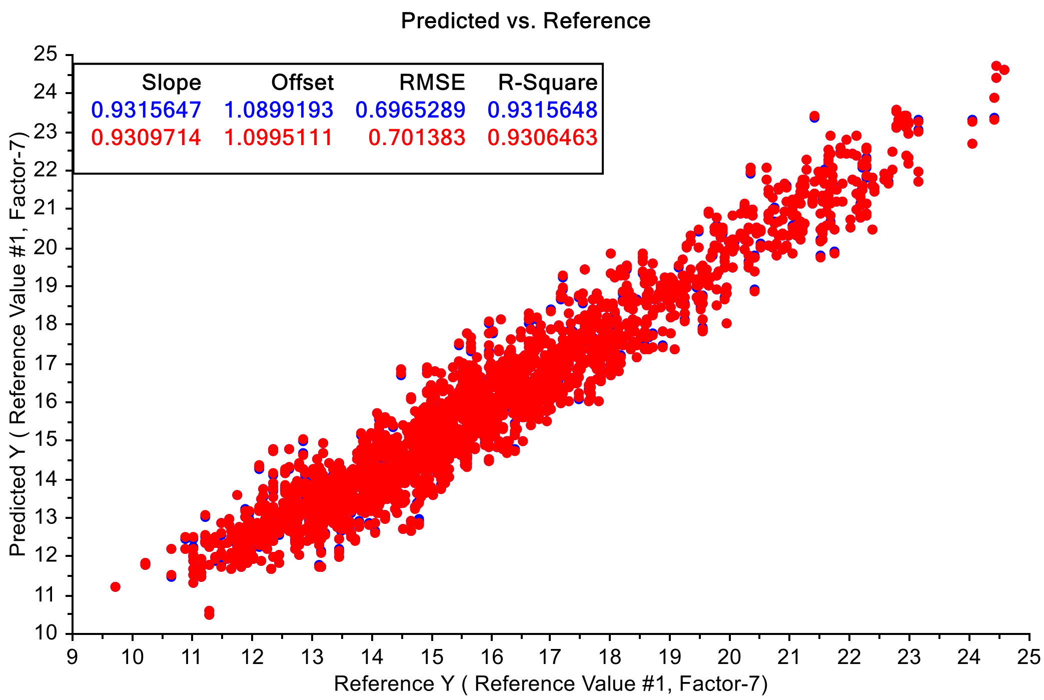


Figure 9. PLSR model calibration (cross validation) results for a combined KP, Calypso, R2E2 and HG population (fruit at different stages of ripening) (n = 400).

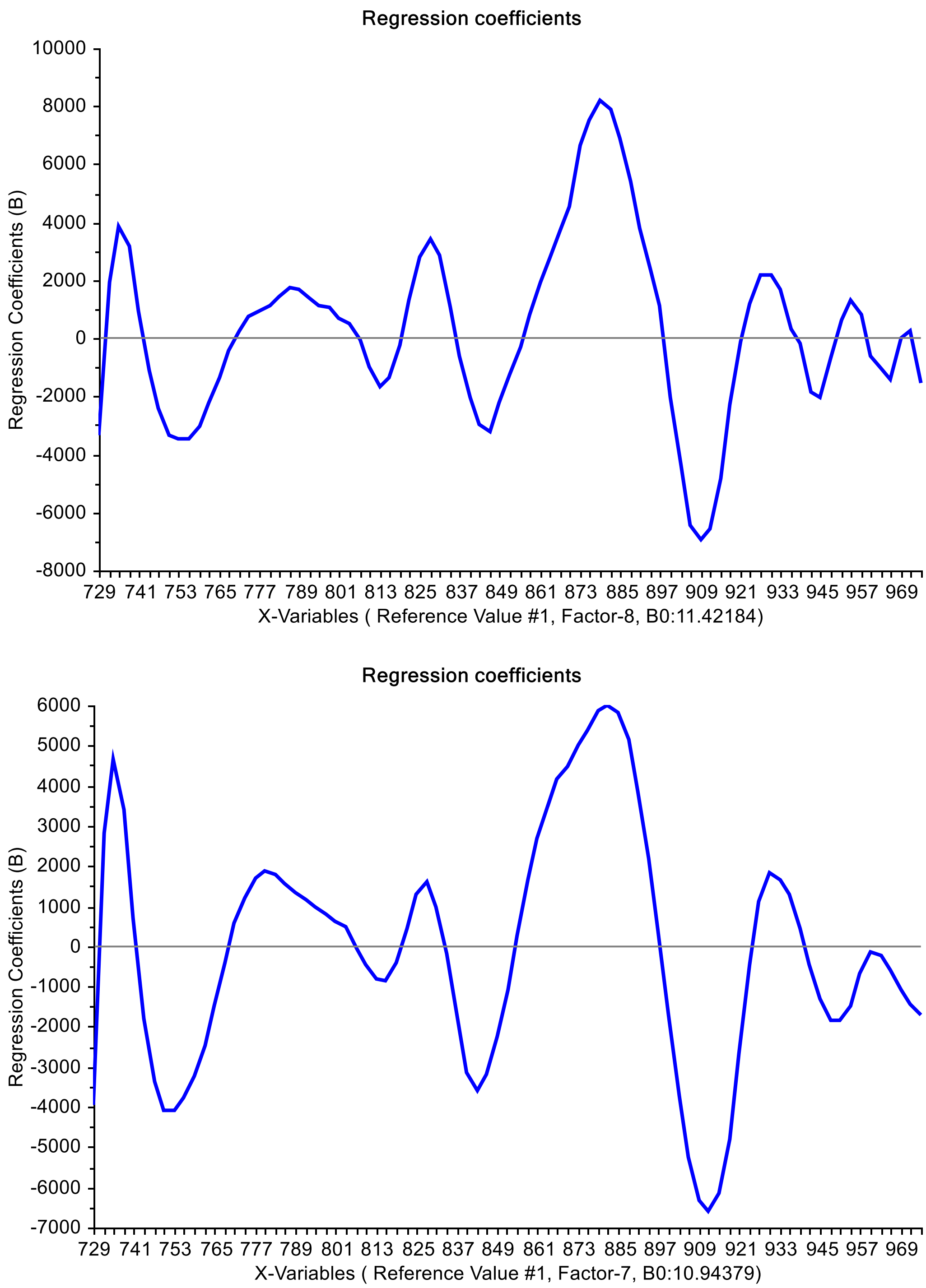


Figure 10. PLSR model b-coefficients for (top panel) a KP DM model, and (bottom panel) the combined KP, Calypso, R2E2 and HG model.

Reasonable results were obtained for prediction of KP, Calypso and HG with models based on fruit of other varieties (data not shown). Keitt appeared to 'differ' from other varieties, with prediction of Keitt fruit slightly improved over single variety models for models developed across several varieties (Fig. 11; e.g. R2 = 0.81, SEP = 0.7, bias = -0.9 % DM), but still poor in terms of bias. Validation of a global model containing data of all varieties on an independent validation set is required.

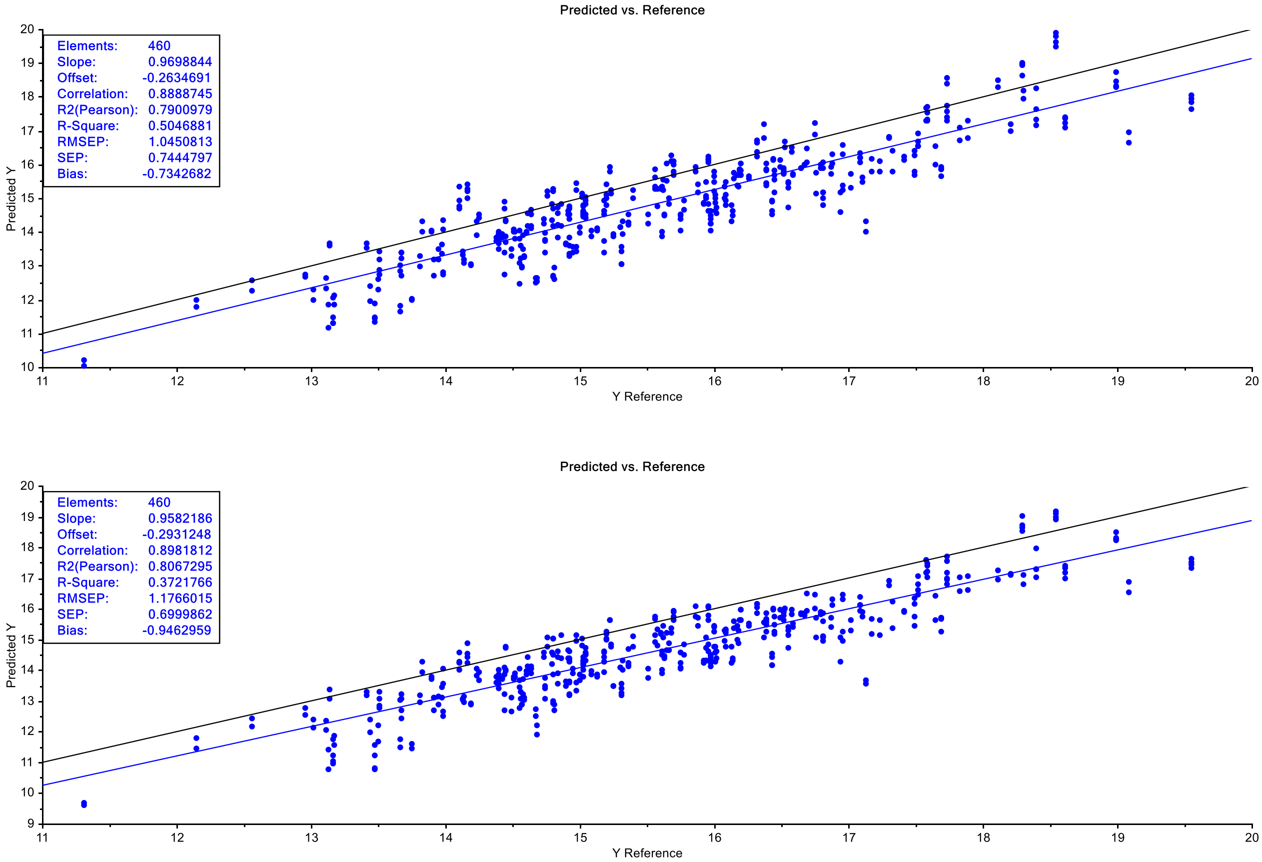


Figure 11. Prediction of DM in Keitt fruit at different stages of ripening using a PLSR model based on (top panel) Calypso and KP fruit at different stages of ripening (R^2 = 0.79, SEP = 0.7%DM bias = -0.7%DM) and (bottom panel) Calypso, KP, R2E2 and HG fruit at different stages of ripening (R^2 = 0.81, SEP = 0.7%DM bias = -0.94%DM).

On sampling numbers

Sampling is a statistical exercise! Two issues are raised for consideration:

(i) AMIA has a set a minimum DM specification on fruit, at which fruit are considered just acceptable for eating quality. However, lot average, assessed of incoming consignments in markets, is being reported in Mango Matters in context of this specification. It is not clear that industry recognises that a lot average of 15 will have 50% of fruit at DM levels below 15, and a typical population SD of 1 to 1.5, substantial numbers of fruit will be below 14%DM. A stricter 'quantile' specification, e.g. 90% of fruit about 15%DM (or other desired level), might be considered.

(ii) Given the variation (SD) of DM between fruit in a lot, there is a sampling error in estimation of lot average. A useful formulae is:
$n = (t.SD/e)^2$
where n is required sample number, t is t statistics for a desired confidence interval (e.g. 1.96 for CI 95%), SD is the standard deviation of the population and e is the accepted error.
For a population with SD of 1.5%DM, a 95% CI, then
for e = 0.2% DM, 225 fruit required
for e = 0.3% DM, 100 fruit required

for e = 0.6% DM 25 fruit required
for e = 0.8% DM, 14 fruit required

Given that the NIR method has an error (SEP) of around 0.6% DM, a generic sampling number target of >25 per consignment or lot is recommended.

Conclusions

PLSR models can be developed for non-invasive assessment of DM in mango fruit at different stages of ripening up to (and slightly past) eating stage. Estimation of DM in over-ripened fruit using NIR models based of spectra collected of fruit at a range of ripening stages is not recommended, but such assessments are not of practical concern.

Model performance on independent populations is encouraging (i.e. R^2>0.8) but as a secondary method, a system of quality control on performance, and model update if necessary, is recommended. At this time, individual models per variety are being used, with bias issues in particular noted in use of models across varieties. There is scope for combined variety models, at least across some varieties, but further work is recommended. Model transfer across instruments is a priority concern, to improve practical deployment of the technology.

The statistics of sampling should be considered in assessing specification compliance, with reporting of % of fruit below a specification value within a lot rather than reporting of a mean. Sampling of at least 25 fruit per consignment/lot is recommended given typical attribute variation (SD=1.5% DM).