Non-destructive measurement of internal browning in Mango

GreenCHAINge Vegetables & Fruits WP1
BO-29.03-001-010

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Summary

The general objective in GreenCHAINge Vegetables & Fruits Work package 1, is to develop a more generic quality control system for the Albert Heijn (AH) supply chain that will improve the assurances for consistent quality. One of the subprojects is the study of mangoes, being one of the tropical products delivered to AH and serving as a model for other tropical products with the AH fresh food logistics.

Mangoes produced in Brazil are transported in reefer containers to the Netherlands. To obtain uniform and RTE (Ready to Eat) mangoes on the shelf in supermarkets, it is essential to:

- Deliver mangoes without internal defects like internal browning
- Deliver uniform and RTE mangoes at the right moment

To optimise decision making in the mango supply chain and decrease post-harvest losses, it is important to develop non-destructive methods for reliable classification of mangoes based on the level of internal defects. A non-destructive method to determine quality of fruits and vegetables is NIRs (Near infrared spectroscopy) technology.

The aim of this study is to measure internal mango quality based on non-destructive measurements. This will enable Albert Heijn, Bakker Barendrecht, Maersk Line and VEZET to define optimal harvest time, transport and ripening conditions, and to select the best raw material for the processing of cut fruit salads.

Our results show that NIR spectroscopy enables non-destructive measurement of the level of internal browning from different mango cultivars, harvested at different orchards and at different harvest moments. Based on a support vector machine (SVM) model, mangoes were classified as "healthy" versus "brown", with an accuracy of 85%. Robust and reliable classification using non-destructive methods could improve quality decisions throughout the mango supply chain, thereby reducing post-harvest losses.

This document is the result of a study, as part of GreenCHAINge Fruit & Vegetables work package 1. This study is executed from September 2015 till December 2018 by researchers of Wageningen Food & Biobased Research (WFBR), who performed an objective and independent study for Albert Heijn, Bakker Barendrecht, Maersk Line and VEZET, who partly financed this project.

This report is confidential until October 2019 and intended only for Albert Heijn, Bakker Barendrecht, Maersk Line and VEZET. From October 2019 onwards the information is public.

1 Introduction

The general objective in GreenCHAINge Vegetables & Fruits Work package 1, is to develop a more generic quality control system for the Albert Heijn (AH) supply chain that will improve the assurances for consistent quality. One of the subprojects is the study of mangoes, being one of the tropical products delivered to AH and serving as a model for other tropical products within the AH fresh food logistics chain. Mangoes produced in Brazil are transported in reefer containers to the Netherlands. To obtain uniform and RTE (Ready to Eat) mangoes on the shelf in supermarkets, it is essential to:

- Deliver mangoes without internal defects like internal browning
- Deliver uniform and RTE mangoes at the right moment

Upon arrival at European wholesalers, mangoes are classified based on their ripening stage and quality. A substantial amount of fruits have internal defects or are misclassified. Pallets are rejected by the processing industry in case internal browning is observed in over 5% of the mangoes[1]. This leads to food waste and decreases the profits in the mango supply chain.

In WFBR report 1663 (Westra *et al.*, 2016) the brown colouration of cut mango fruits was studied for mangoes harvested in a browning-insensitive period (March 2016) and a browning–sensitive period (April 2016). The "incidence of brown discolouration" and the "acoustic firmness", correlated with the internal maturity stage. Balancing between a certain maturity while minimizing issues with respect to brown discolouration remains a challenge. In WFBR report 1737 (Gabriëls *et al*., 2017) the firmness, DM (Dry Matter), BRIX (or SSC (Soluble Sugar Content)), internal colour and internal browning were measured on more than 3000 mangoes transported in nine different shipments between November 2016 and January 2017 from Brazil to The Netherlands. Acoustic firmness measurements enabled the measurement of the RTE (Ready to Eat) stage, facilitating supermarkets like AH, as well as fruit processing companies like VEZET, to deliver more homogeneous batches. Although internal browning was hardly observed, data from extended storage at higher temperatures (> 20°C) indicated that internal browning correlates to a decreased firmness, and an increased internal colour.

In this study we assessed internal browning in batches of mangoes for which internal defects are expected; either because those batches were rejected by the processing company, or because they were stored for deliberately chosen extended time periods and high temperatures. In those batches of mangoes we investigated whether the level of internal browning can be predicted by a non-destructive measurement based on NIR spectra. A support vector machine (SVM) model was built based on both NIR spectra of intact fruits and images of mango halves. Using colour analysis software, the images were analysed to determine the level of internal browning.

Our results show that NIR spectroscopy enables non-destructive measurement of the level of internal browning from different mango cultivars, harvested at different orchards and at different harvest moments. Based on a SVM model, mangoes were classified as "healthy" versus "brown", with an accuracy of 85%. Robust and reliable classification using non-destructive methods could improve quality decisions throughout the mango supply chain, thereby reducing post-harvest losses.

1.1 Goal

The aim of this study is to predict internal mango quality based on non-destructive measurements. This will enable Albert Heijn, Bakker Barendrecht, Maersk Line and VEZET to define optimal harvest time, transport and ripening conditions, and to select the best raw material for the processing of cut fruit salads.

[1] Personal communication from VEZET

1.2 Research question

The main research question is: can we predict the presence or absence of internal browning in mangoes by non-destructive measurement based on NIR spectra?

2 Materials and Methods

Fruit material
Mango (*Magnifera indica* L.) fruit of cultivar "Keitt" was harvested in a commercial orchard in the Petrolina area in Brazil and transported to the Netherlands in a reefer container oversees, for three weeks at a temperature of approximately 10°C. Subsequently, mangoes were sorted based on their ripening stage at a wholesale company and transported to a processing company at approximately 12°C during three hours.

Mango fruits of cultivar "Kent" were harvested in the South of Peru. Mangoes arrived at WFBR after three weeks of transport oversees in a reefer at a temperature of approximately 10°C.

Research on Keitt mangoes from rejected pallets
Upon arrival, at the processing company, as part of the daily routine, mangoes are subjected to a quality check by an in-house qualified person. A random subset of twenty mangoes per pallet is cut in halves, in order to visually judge internal quality. In case over 5% of the mangoes is showing internal defects, a batch is rejected. Rejected batches are discarded or sold at local markets[2].

A number of rejected pallets obtained in the period between Sept and Dec 2017 were transported to Wageningen Food & Biobased research (WFBR) for further research. Transport to WFBR took approximately three hours and was done without temperature control. Rejected pallets arrived at WFBR at September 27th, October 9th and November 29th of 2017, containing respectively 230, 108 and 264 mangoes of cultivar Keitt. Subsequently, a range of quality measurements was performed. This included NIR spectra acquisition from both sides of the intact fruit. After that, subjective evaluation and objective measurement of internal colour and internal breakdown was performed. For this, mangoes were cut alongside both sides of the seed.

In general, measurements were done on both mango sides. However, for the first rejected pallet of 230 mangoes, only one side of the mango fruit was used for quality measurements. For the third rejected pallet, containing 264 mangoes, subjective evaluation of internal brown was not recorded.

Research on Kent mangoes to induce internal browning
In April 2018, over 600 mangoes of cultivar Kent arrived at WFBR. Mangoes were randomized and divided in groups of 42 fruits. Subsequently, fruit was stored for either 6, 10, 16 or 22 days at 6, 10, 16 and 22°C. Quality measurements were done on individual fruit for all temperature-time combinations. These measurements included NIR spectra acquisition, subjective evaluation and objective measurement of internal colour and internal breakdown.

The applied storage time and storage temperature combinations were computed in degree-days, the so-called T_{sum} (temperature* time in °C*days), to visualize the impact of the treatment. Previous history is not taken into account in this measure.

Spectra acquisition
NIR spectra were collected from both sides of the intact fruit on the equatorial region, with equal distance from proximal and distal ends as described by Santos Neto *et al*. (2017) and Subedi *et al*. (2007). A FELIX750 handheld NIR device was used to collect short wavelength NIR (SWNIR) spectra, with a wavelength range of 300 to 1100 nm.

Subjective evaluation of colour and internal browning
Internal colour of both halves was evaluated using a five-point scale: stage 1 (white/light yellow) till stage 5 (dark yellow/orange) (Figure 1) and internal breakdown was scored as estimated percentage of the cut surface on the mango halves.

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[2] Personal communication from VEZET

The percentage of internal breakdown in the mango pulp was subjectively measured by estimating the surface containing brown tissue as percentage of the total cut surface of each mango halve.

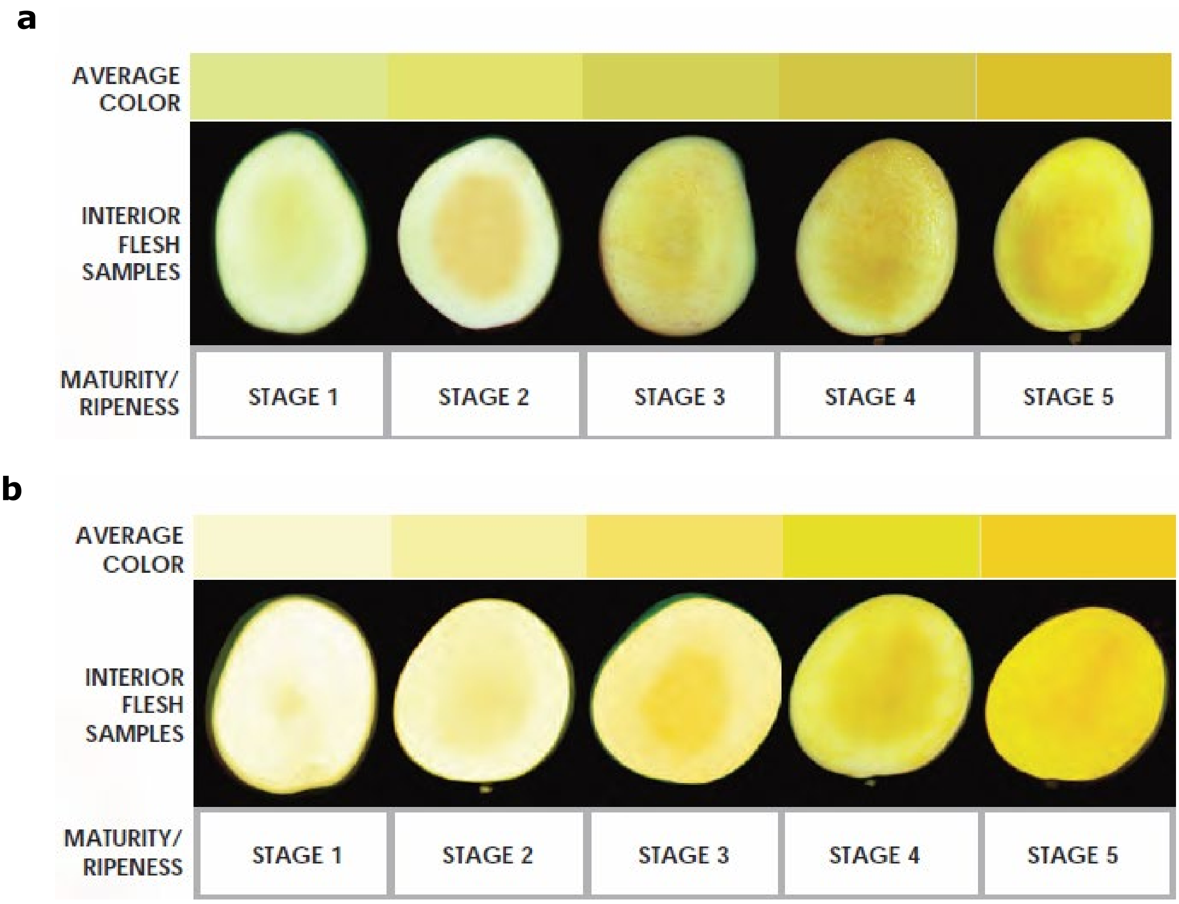

Figure 1: Mango internal colour scale for cultivars Keitt (a) and Kent (b) from stage 1 (white/light yellow) to stage 5 (dark yellow/orange).[3]

Objective measurement of internal colour and internal browning
After evaluation, objective measurements of internal colour and internal browning were performed in a light and colour-standardized cabinet. The flesh of each mango half was photographed using a digital camera (AV MAKO G-503C POE with a 1/2.5" CMOS Sensor and a KOWA LM6JC lens), mounted in the light cabinet, equipped with Condormatic LED panels, type Galaxy. The colour-standardized pictures were analysed for colour in a two-step approach. First, using colour-learning software, colours of the mango pulp were associated to either healthy mango tissue or tissue with internal defects. Green colours were associated to the peel and were excluded from further analysis. Second, colour analysis software determined the area of mango half related to healthy tissue and to non-healthy (brown) tissue. To get a measure of the level of internal browning, the ratio of healthy to brown tissue was calculated, based on the areas. The distribution of this ratio appeared to be very skewed. In order to get a better distinction in the degree of internal browning, the natural logarithm (Ln) of this ratio was used in further analysis. The level of internal brown is defined as the LnHB (Healthy-Brown) ratio. Since in industry mangoes will be sorted as either "good = healthy" or "bad = brown", we decided to classify into two classes. Mangoes with an LnHB below 2.5 were defined as "brown" and mangoes with an LnHB of 2.5 or more as "healthy". This boundary between good and bad was chosen by visual inspection of the images of mango halves suffering from different degrees of internal browning and was approved by Bakker Barendrecht.

Model building
A support vector machine model was built to allow classification of mangoes into classes with internal brown in the mango pulp (LnHB ratio <2.5) or with hardly or no internal brown in the mango pulp

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[3] https://www.mango.org/research-post/mango-maturity-and-ripeness-guide/

(LnHB ratio≥2.5). The model was built using either data from Keitt or Kent mangoes, and using the combined dataset of both Keitt and Kent mangoes. This resulted in a total dataset of NIR measurements and objective measurements of the level of internal browning of 2234 mango halves. The total dataset consists of subsequently 230 mango halves from the first rejected pallet (for which only one mango half was measured), 216 mango halves from the second rejected pallet and 528 mango halves from the third rejected pallet. This, in addition to the 1260 mango halves from cultivar Kent, deriving from the "time-temperature" experiment.

Statistical analysis
Data was analyzed using the analysis of variance (ANOVA) In Genstat 19th edition and the means compared using the Bonferroni post hoc test test with 5% probability.

3 Results

3.1 Internal browning in Keitt mangoes, from rejected pallets

Figure 2 shows examples of individual fruit halves and their corresponding LnHB. Fruits with an LnHB under 2.5 suffer from severe internal browning.

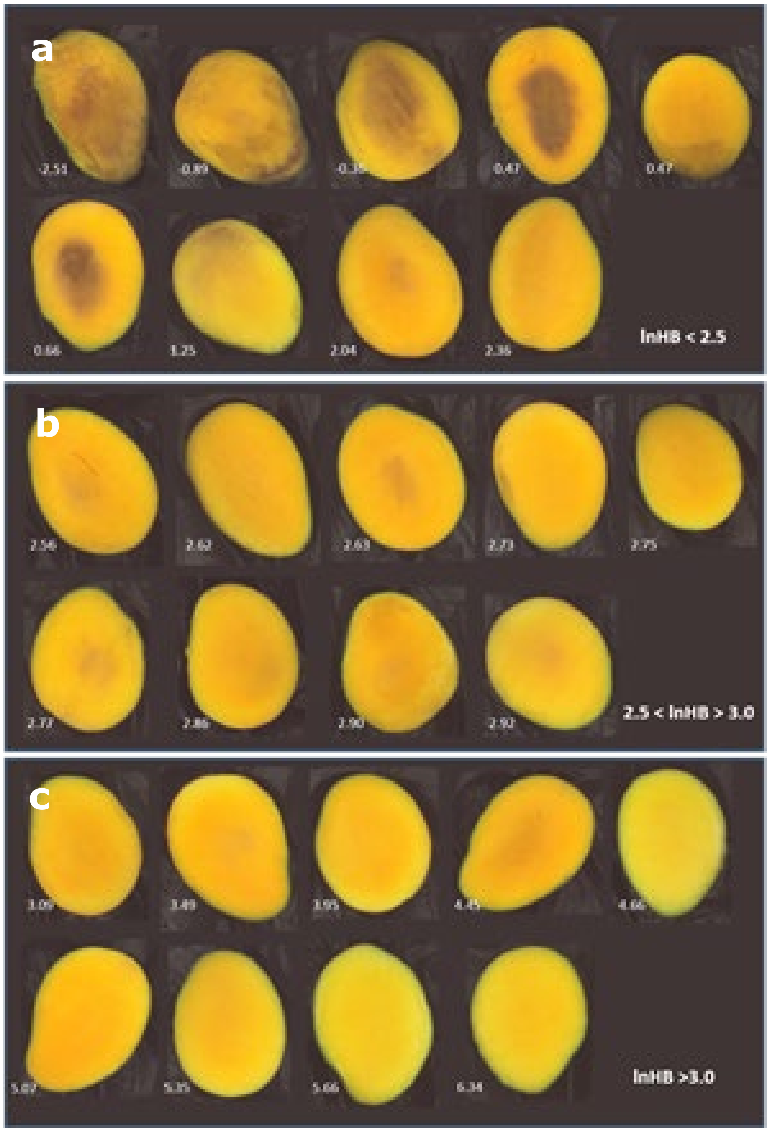

Figure 2: Colour standardized images of Keitt mangoes with internal browning and the corresponding LnHB ratio: a) LnHB<2.5, b) LnHB between 2.5 and 3.0, c) LnHB>3.0. Images were taken in the light cabinet

Figure 3 shows a frequency distribution of the LnHB ratio of the Keitt mangoes from the three rejected pallets. Most mangoes of the first (a) an third (c) rejected pallet have a LnHB ratio below 2.5, indicating most mangoes showed internal defects. In contrary, more mangoes of the second (b) rejected pallet have a LnHB ratio of 2.5 or more and can be classified as healthy.

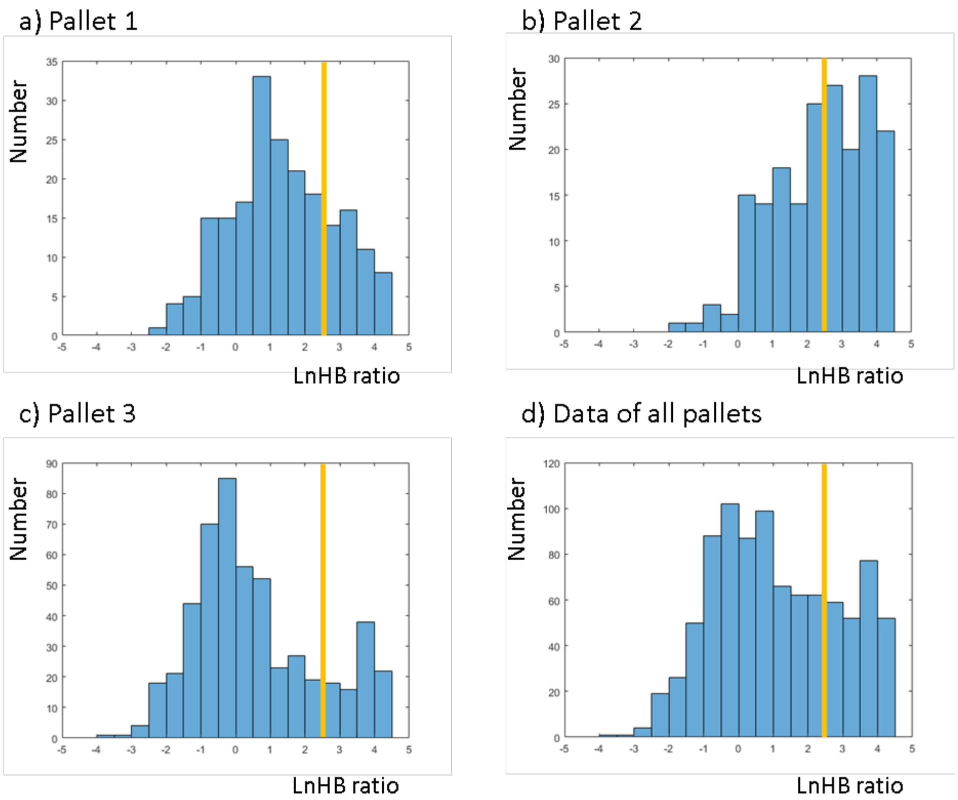

Figure 3: Frequency distribution (number of fruits) of the LnHB ratio of mangoes from respectively pallet 1 (a), 2 (b) and 3 (c), and from all three pallets (d). Orange line indicates the boundary of LnHB ratio of 2.5.

3.2 Internal browning in Kent mangoes, a time-temperature experiment

Since storage time at higher temperature induces ripening in mangoes, it was anticipated that an extended storage period at high temperate would induce internal browning. As expected, the intensity of the internal yellow colour increased at longer storage periods and higher storage temperature (Figure 4), indicating increased ripening.

No internal browning was observed at low storage temperature (6°C) upon storage up to 16 days. Furthermore, no internal browning was observed upon storage for 6 days at any of the temperatures. Internal browning became clearly visible at the 10-16 combination (T_{sum} = 160: 10 days at 16°C or 16 days at 10°C). Internal browning increased with longer storage time and/or higher storage temperature. Internal browning was most severe after the longest storage period, 16 and 22 days, at the highest storage temperature 22°C. Mangoes stored for 22 days at 22°C were too rotten to handle (no picture available).

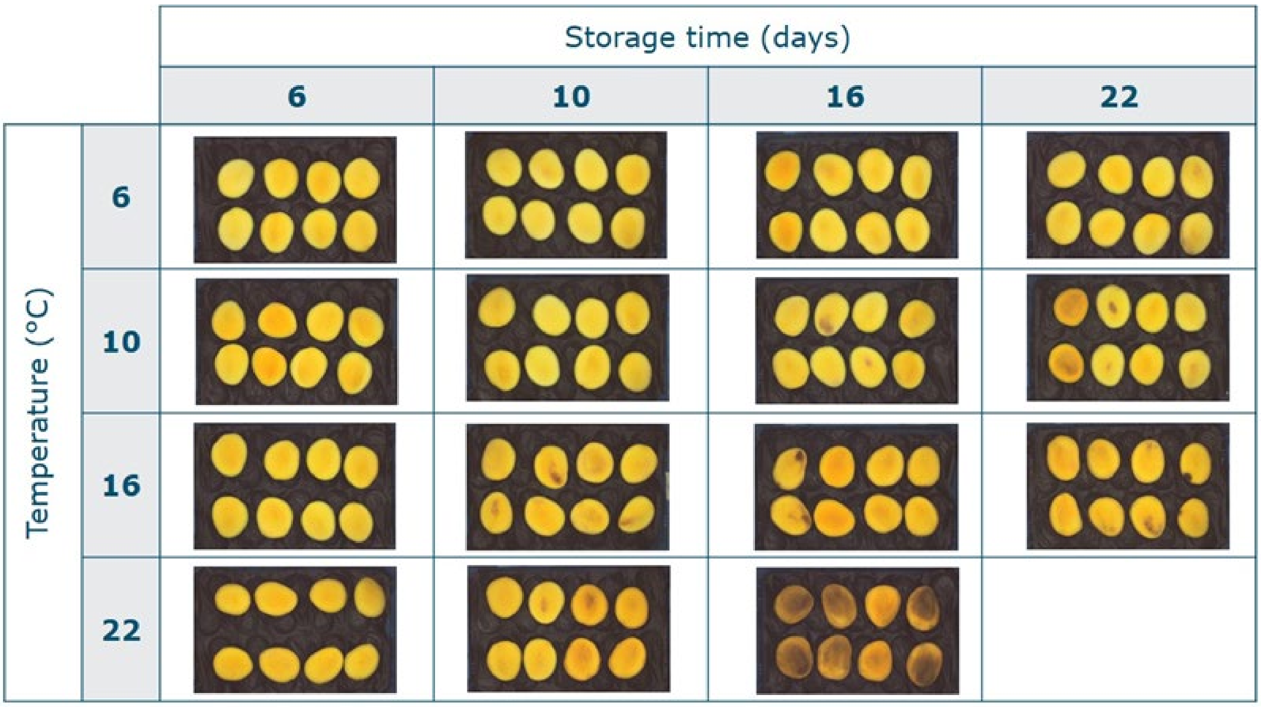

Figure 4: Colour standardized images of Kent mangoes stored for 6, 10, 16 and 22 days after arrival at WFBR, at 6, 10, 16 and 22 °C (no picture available for the mangoes stored 22 days at 22 °C). Images were taken in the light cabinet.

The percentage internal browning increases with an increased T_{sum} (Figure 5). The highest percentage internal browning is observed at a T_{sum} of 352 when stored during 16 days at 22 °C. However, the percentage of brown tissue in the reciprocal combination, 22 days at 16°C, is less severe. This might indicate that temperature has more effect on internal browning than storage time.

Recommended storage temperature is 13°C for mature-green mangoes en 10°C for partially-ripe and ripe mangoes[4] . In this experiment, at 6°C storage temperature, chilling injury could happen. Chilling injury incidence and severity depend on cultivar, ripeness stage (riper mangoes are less susceptible) and temperature and duration of exposure. Symptoms of chilling injury include uneven ripening, poor colour and flavour, surface pitting, greyish scald-like skin discoloration, increased susceptibility to decay, and, in severe cases, flesh browning. Storage at 6°C for up till 22 days did not reveal external or internal symptoms of chilling injury in these fruits.

[4] Adel A. Kader, 1997. Perishables Handling #89, Mango, Recommendations for Maintaining Postharvest Quality http://postharvest.ucdavis.edu/Commodity_Resources/Fact_Sheets/Datastores/Fruit_English/?uid=37&ds=798 (Accessed date 2018-02-22)

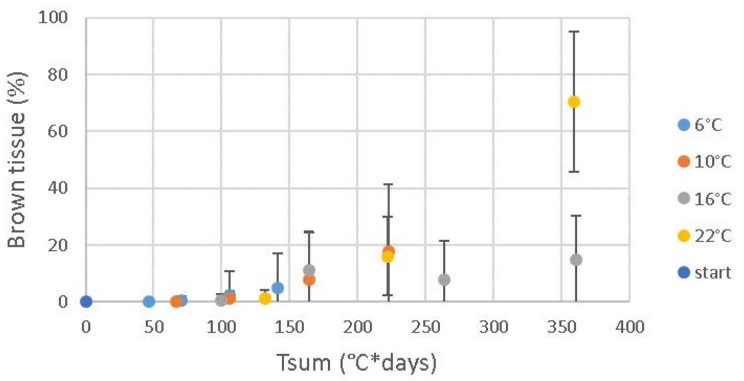

Figure 5: Averaged internal browning (%) of Kent mangoes as a function of the T_{sum}; bars show standard deviation.

3.3 Non-destructive classification in healthy versus brown mangoes

To classify mangoes in the two classes, healthy and brown, the short wavelength NIR (SWNIR) spectra were correlated to the level of internal browning, defined by the LnHB ratio. This procedure was done both for the Keitt mangoes from the rejected pallets as well as for the Kent mangoes from the time-temperature experiment.

To investigate correlations between the NIR spectra and the level of internal browning, a SVM model was built. To train and test (validate) the model, the mangoes were divided in a so called training- and test-set (Figure 6). First, the model was trained using 70% of the NIR spectra and LnHB ratios, this dataset is called the training-set. Second, the model was validated using 30% of the NIR spectra, called the test- or validation-set. In this test-set, the NIR spectra were used to predict the LnHB ratio of the corresponding mango.

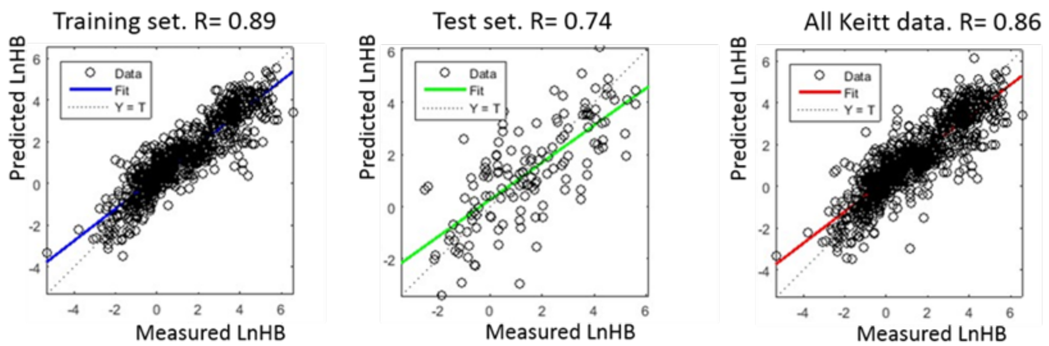

Figure 6: Regression using NIR spectra and LnHB ratios, calculated based on objective measurements of the level of internal browning, in the training-set, the test-set, and all data from all Keitt mangoes from the three rejected pallets.

In the training set, the correlation coefficient[5] R is 0.89, and the determination coefficient[6] R^2 is 0.79 (Figure 6). For the test set the R is 0.74 and the R^2 is 0.54. Finally, using all data from the three

[5] R: the correlation coefficient: a measure of how strongly a pair of variables are related and the direction of the relation (positive or negative); They all assume values in the range from −1 to +1, where +1 indicates the strongest possible agreement and −1 the strongest possible disagreement (https://en.wikipedia.org/wiki/Correlation_coefficient)

[6] R^2: the coefficient of determination: a measure how variance in y is explained by the model; an R^2 of 0.85 means that 85% of the total variation in y can be explained by the linear relationship between x and y (as described by the regression equation). The other 15% of the total variation in y remains unexplained (https://en.wikipedia.org/wiki/Coefficient_of_determination)

rejected pallets, the model allowed the prediction of the LnHB ratio based on the measured NIR spectra explaining 74% of the variation (R=0.86 and R^2=0.74).
Subsequently, all Keitt mangoes were classified in a so called "confusion matrix" with the following prediction accuracy (Figure 7):

- Mangoes which were predicted by NIRs to be "brown":
    - proved to be truly "brown" in 80% of the cases,
    - while 20% proved to be "healthy" (false negatives).
- Mangoes which were predicted by NIRs to be "healthy":
    - proved to be truly "healthy" in 89% of the cases,
    - while 11% proved to be "brown" (false positives).

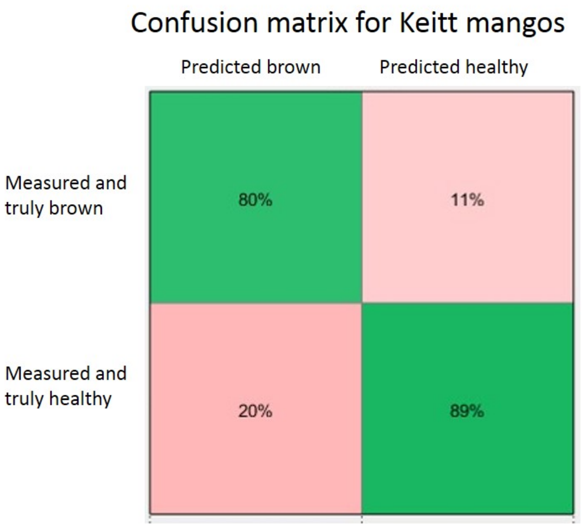

Figure 7: Confusion matrix for Keitt mangoes showing false (pink) or true (green) predictions of brown or healthy mangoes.

For Kent mangoes, for which internal browning was induced upon storage at different time and temperature combinations, a similar model was built. In this case, the confusion matrix shows that brown mangoes were correctly predicted to be brown in 88% of the cases, with 12% of false negatives, while healthy mangoes were correctly predicted to be healthy in 87% of the cases, with 13% of false positives (Figure 8).

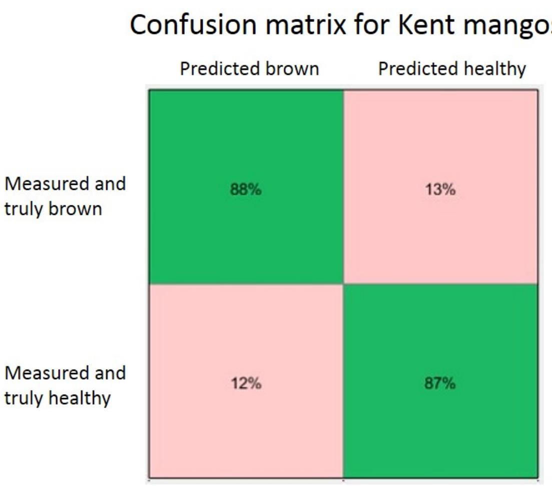

Figure 8: Confusion matrix for Kent mangoes showing false (pink) or true (green) predictions of brown or healthy mangoes.

Finally, a SVM model was made based on the NIR measurements and level of internal browning of the complete dataset of 2234 mango halves of either cultivar Keitt or Kent (Figure 9). Based on this model, mangoes could be classified as truly brown in 85% of the time, and truly healthy in 88% of the times.

These results show that **NIR spectroscopy enables non-destructive prediction of internal browning in two mango cultivars, harvested at different orchards and at different harvest moments.** This is in line with Nordey *et al*. (2017), who described prediction of a range of other mango quality traits among different mango cultivars and a variation of pre- and post-harvest environments. In industry, most mangoes are sorted with a 50% chance of misclassification[7]. Instead of sorting using linear regression models, we propose to classify mangoes using an SVM model. **Classification of these mangoes based on an SVM model, allows quality decisions in the mango chain with >85% accuracy.**

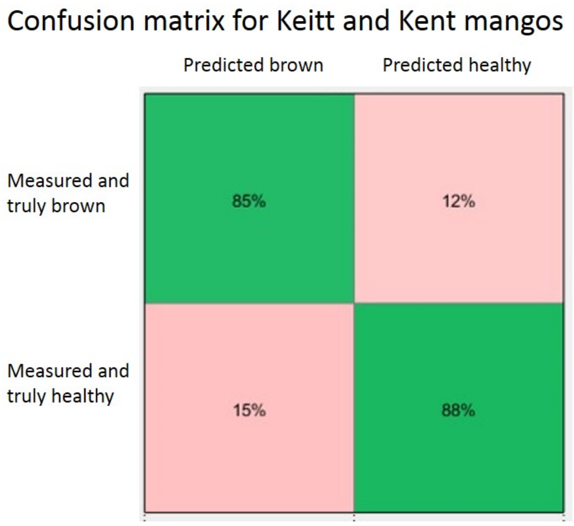

Figure 9: Confusion matrix for Keitt and Kent mangoes: showing false (pink) or true (green) predictions of brown or healthy mangoes.

[7] Personal communication BakkerBarendrecht

4 Discussion and conclusions

So far, NIR models for mango were described for traits like DM, SSC-content, firmness or flesh colour. **For the first time**, we assessed **an internal quality issue:** internal browning in mangoes. We investigated whether **prediction of the level of internal browning based on NIR spectra would be feasible.** The level of internal browning was defined by the LnHB ratio. A learning by comparison model using SWNIR spectra of 2234 mango halves was used to classify mangoes into healthy, with an LnHB ratio of 2.5 or more, versus brown, with an LnHB ratio lower than 2.5. From this we conclude that the Felix handheld VIS-NIR spectrometer can be used to classify mangoes based on the level of internal brown, with an accuracy of 85% using an optimised learning by regression model.

For application in industry it is good to realize that with an accuracy of 85%, still 15% of the mangoes will be misclassified (false negatives). Meaning that 15% of the yield, thus profit, will be unnecessary discarded. It remains questionable whether this is desired for mangoes of good quality, especially if the production and transport conditions were optimal.

Of course, the boundary of LnHB which was set at 2.5 to classify mangoes in either “healthy” or “brown” could be adjusted to the demands of the industry. Increasing the LnHB boundary, would lead to a stricter sorting in which hardly any level of internal browning is allowed in a mango. This would be an advantage for the processing industry since there is a high probability that mangoes classified as healthy will be truly healthy. However, the percentage mangoes classified as brown while they are in fact healthy will be higher, leading to the discarding of good quality fruits and thus more waste and less profit for the wholesaler.

So, setting the boundary to classify mangoes depends on the desires of both the wholesaler and the processing company. Furthermore it is worthwhile to take the origin and the transport conditions into account. For example, if mangoes come from orchards with adverse pre-harvest conditions due to heavy rain fall or high humidity, or if they are transported under less optimal conditions due to technical failure or delays, those mangoes are expected to have internal defects. In that situation a certain percentage of misclassification might still be economically worthwhile.

In conclusion, a robust and reliable classification system using non-destructive methods could improve quality decisions throughout the mango supply chain, thereby reducing post-harvest losses. Instead of handheld NIR devices, automated NIR measurements are recommended for high throughput sorting of mangoes at wholesalers. Further research using automated NIR measurements, instead of hand-held devices, is required before implementing high throughput classification of mangoes at the wholesaler.

5 Literature

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Report 1914

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