Original article

Postharvest behavior of mangoes nondestructively sorted based on dry matter content during and after storage under controlled atmosphere

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Summary

Introduction – **As maturity plays an important role during controlled atmosphere (CA) storage, the objective of this study was to evaluate if mangoes sorted based on visual characteristics behave differently during CA storage than mangoes sorted based on 150 g kg^{-1} dry matter (DM) content using near-infrared (Vis-NIR) spectrometer.** *Materials and methods* – **'Palmer' mangoes were harvested and DM predicted by partial least squares regression (PLSR). Fruit quality was evaluated at harvest, after 30 d of CA storage, and after 30 d plus 4 d at ambient conditions.** *Results and discussion* – **PLSR model developed with fruit from 2015/2016 and 2016/2017 seasons was able to predict DM content from mangoes produced in a different region (Petrolina, PE), but with high root mean square error of prediction (RMSEP = 20.2 g kg^{-1}) and low R^2_P (0.19). Therefore, Vis-NIR spectra from mangoes produced in Petrolina, PE were incorporated into the data set and a new model was developed ($RMSE_V$ = 13.8 g kg^{-1}, and R^2_V = 0.63). With the new PLSR model it was possible to sort mangoes produced in Petrolina, PE with 150 g kg^{-1} DM. Quality differences were not observed between fruit sorted based on 150 g kg^{-1} DM and based on visual appearance. However, the mangoes sorted based on 150 g kg^{-1} DM presented lower standard deviation, indicating a more homogeneous fruit batch.** *Conclusion* – **The use of portable Vis-NIR spectrometer allows a more uniform sorting of mangoes, which can be used to improve the quality of mangoes that reach the consumer.**

Keywords
chemometrics, dry matter, *Mangifera indica* L. 'Palmer', partial least squares regression, portable visible-near infrared (Vis-NIR) spectrometer

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Significance of this study

What is already known on this subject?

- Mango maturity can be accurately predicted based on dry matter (DM) content using portable near-infrared (Vis-NIR) spectrometers.

What are the new findings?

- This is the first report regarding sorting mangoes based on DM content prior controlled atmosphere (CA) storage. The use of portable Vis-NIR spectrometer allows more uniform mango batches based on DM content (150 g kg^{-1} DM).

What is the expected impact on horticulture?

- As use of portable Vis-NIR spectrometer allows sorting mangoes with more uniform DM content (150 g kg^{-1} DM). Therefore, the mango industry can offer to consumers uniform mango batches, which potentially can reduce fruit losses, with greater quality and acceptance.

Introduction

Brazil is the world's seventh largest producer of mangoes (Mitra, 2016), with a production of 976,815 metric tons in an area of 64,305 hectares in 2015 (IBGE, 2015). Mango is the most exported fruit from Brazil with 154,211 tons exported in 2016, which generated an estimated income of USD 179,932,175 (MAPA, 2016).

Traditionally, mangoes are harvested when they are physiologically mature, which is determined based on visual appearances (color, fullness of cheeks, and hardened endocarp), and are immediately transported to the packing-house where fruit are unloaded into a tank with chlorinated (0.1 g L^{-1}) water (Neto *et al.*, 1994). Defective fruit are removed on a conveyor belt and the peduncle is trimmed to a length of 5 cm. To avoid sapburn, the fruit are immersed in calcium hydroxide solution (4.0 g L^{-1}) for up to 4 minutes. Fruit are then waxed with carnauba wax, dried in a hot air tunnel (45 °C) and brushed. Subsequently, mangoes are sorted based on defects and weight, put into carton box trays (3.50 × 2.85 × 1.05 cm) with 4 kg capacity, palletized, and air cooled for 4–6 h. Shipments to international markets are generally sent by air and/or ship freight. Although the traditional handling follows the technical postharvest recommendations for mango handling (Neto *et al.*, 1994; Kader, 2003a), it does not sort the fruit based on internal chemical characteristics, which might be the cause of quality problems in export markets. For example, in the USA market, the quality of Brazilian 'Tommy Atkins' mangoes were considered inferior to that of Mexican fruit (Makani, 2013), mainly because of lower soluble solids content (SSC), which affects consumers preferences.

As the content of dry matter (DM) in fruit is well correlated to fruit SSC and eating quality (Whiley *et al.*, 2006), the Australian Mango Industry Association (AMIA) has recommended minimum DM levels as standards. Owen and Moore (2013) recommended a DM content of 140 g kg^{-1}, but this value has been recently increased to 150 g kg^{-1} for 'Kensington Pride', 'Calypso', 'R2E2', and 'Celebration' (Walsh, 2016). To sort mangoes using DM and/or other quality parameters prior export, fruit evaluation needs to be done with non-destructive methods, and near-infrared spectroscopy (NIRS) has long been recommended for this purpose (Abbott, 1999). Portable near infrared (NIR) spectrometers have been used to estimate quality parameters in mangoes of different cultivars (Walsh and Subedi, 2016; Santos Neto *et al.*, 2017) and are becoming more important in field applications.

At ambient temperature, mango ripens rapidly, and fruit quality can be maintained no longer than 8 d (Kader, 2003a). Low temperatures can extend mango shelf-life to around 16 d. However, mango preservation in traditional refrigeration systems is not completely safe because mangoes are susceptible to chilling injury at temperatures lower than 13 °C (Mitra and Baldwin, 1997). Controlled atmosphere (CA) in association with low temperature can improve mango storability and maintain fruit quality during long term storage (Kader, 2003a, b). Storage under CA has been used to extend the shelf-life of a wide range of mango cultivars, including 'Kensington Pride' (McLauchan and Barker, 1992), 'Kent' (Trinidad *et al.*, 1997; Bender and Brecht, 2000), 'Tommy Atkins' (Bender and Brecht, 2000), and 'Haden' (Bender and Brecht, 2000). CA with 5 kPa oxygen (O_2) and 5 kPa carbon dioxide (CO_2) can extend mango shelf-life (Kader, 1986). For instance, Lizada *et al.* (2004) reported shelf-life extension of up to 31 d for 'Tommy Atkins'.

An optimal CA recommendation is not yet available for 'Palmer' mangoes. Teixeira and Durigan (2011) reported that 'Palmer' mangoes can be stored at 12.8 °C in atmospheres with 1–10 kPa O_2 for up to 28 d. Increasing CO_2 concentration up to 25 kPa did not affect 'Palmer' mangoes during storage (Teixeira *et al.*, 2018). Few of the most significant effects of CA in mango are the reduction in the respiration rate, delayed ripening, and maintenance of overall fruit quality. Therefore, maintaining a CA is a promising approach to improve the shipping of 'Palmer' mangoes through maritime transport to distant markets, which may take three or four weeks.

Estimation of the maturity stage of mangoes by means of portable Vis-NIR spectroscopy should be accurate as maturity plays an important role during CA storage. Most studies using CA to extend mango shelf-life were performed with hard mature green fruit (Singh and Zaharah, 2015), and Brecht et al. (2003) reported that mango maturity plays an important role during CA storage. Although studies have reported the use of portable Vis-NIR spectrometers to estimate maturity in mango fruit, how fruit are sorted by NIRS preform in CA is not yet known. Therefore, the objective of this study was to evaluate whether during CA storage mangoes sorted based on visual characteristics differ from mangoes sorted with 150 g kg^{-1} DM as a parameter, which is determined using the calibration models for DM content prediction of 'Palmer' mangoes developed by Santos Neto *et al.* (2017, 2018), and to evaluate the quality changes during the storage period of 30 d, which is similar to the time required to deliver maritime shipments to distant markets.

Material and methods

Plant material

Mangoes (*Mangifera indica* L. 'Palmer') were harvested from the commercial orchards of the Agrobras Agrícola Tropical do Brasil S.A., located at Petrolina, PE (latitude 09°23'55"S; longitude 40°30'03"W, 376 m altitude) in October 2017. The mango trees were planted 8.0 × 5.0 m apart and they were fertirrigated. In 2016/2017 season in Petrolina it was observed an average temperature of 27.1 °C (33.5–22.1 °C), 347.8 mm precipitation, 7.4 hours of insolation, and 57% relative humidity (RH). Fruit were randomly collected from 60 plants with an average of 7 fruits per plant.

Dry matter prediction using portable Vis-NIR spectrometer

Acquisition of Vis-NIR spectra

A total of 420 mangoes were harvested to obtain the Vis-NIR spectra using a portable F-750 (Felix Instruments, Washington, USA), which is equipped with a Carl Zeiss MMS-1 NIR spectrometer. The spectra were obtained on the opposite sides of the equatorial region of the fruit in the wavelength range of 310 to 1,100 nm, using interactance as optic configuration and a resolution of 8–13 nm, according to Santos Neto *et al.* (2017).

Reference analysis

For the determination of DM, samples of 27 mm in diameter and with 10 mm of depth were collected from the same location where the Vis-NIR spectra were obtained. Epidermis (1–2 mm thick) was removed from the fruit using a peeler and the DM content was determined by recording the dry weight of the samples after drying them in an oven at 105 °C for 48 h (Santos Neto *et al.*, 2017).

Prediction of dry matter content by chemometry

Prior to the main harvest, 43 mangoes were obtained in Petrolina, PE and their Vis-NIR spectra and DM content were recorded. These spectra were used as a prediction set based on the partial least squares regression (PLSR) model developed in 2015/2016 and 2016/2017 harvest seasons in Cândido Rodrigues, São Paulo State (Santos Neto *et al.*, 2018). These spectra were pre-processed using different techniques and their combination, such as multiplicative scatter correction (MSC); first and second derivatives of Savitsky-Golay (SG-1 and SG-2); MSC + SG-1; MSC + SG-2; standard normal variate (SNV), De-Trend; SNV + De-Trend. All analyses were carried out using Unscrambler®, version X.3 (CAMO, Oslo, Norway). The performance of each pre-processing was evaluated based on the root mean square error of calibration ($RMSE_C$), validation ($RMSE_V$), prediction ($RMSE_P$), and the determination coefficient (R^2) (Nicolaï *et al.*, 2007).

To improve the robustness of the PLSR model for DM prediction, the fruit from other production region located in

Table 1. Descriptive statistics of dry matter (DM) content in 'Palmer' mangoes sorted based on visual characteristics and with 150 g kg^{-1} DM content using a portable visible near-infrared (Vis-NIR) spectrometer.

Source of variation	Total	Sorted	Average	Maximum	Minimum	SD[1]
Visual sorting	210	149	152.7	207.7	97.5	23.3
150 g kg^{-1} DM	210	61	147.6	165.2	129.5	15.9

[1]SD = standard deviation.

Petrolina, PE were added to the analysis as a source of variation. The Vis-NIR spectra of 43 mangoes were incorporated into the dataset and a new PLSR model was developed using full cross validation in the spectral range of 699–981 nm by either applying or not applying the pre-processing already described (Santos Neto *et al.*, 2017). This new PLSR model was used to sort the mangoes based on 150 g kg^{-1} DM for the CA storage experiment.

CA storage

Immediately after harvest, mangoes ($n = 420$) were sorted based on 150 g kg^{-1} DM threshold using a portable near infrared spectrometer F-750 (Felix Instruments, Washington, USA), according to the recommendations reported by Walsh (2016), and only 61 mangoes from 210 were sorted based on this criterion (Table 1). The fruit were transported to Jaboticabal, SP using air freight. At arrival, the fruit were divided into following two treatments: *i*. fruit were visually sorted as suitable for export markets according to the traditional handling used by the mango growers (color and fullness of cheeks) ($n = 43$), and *ii*. fruit were non-destructively sorted using F-750 portable Vis-NIR spectrometer with 150 ± 13.8 g kg^{-1} DM content ($n = 43$).

Fruit were pre-cooled for 10 h at 13 °C in a cold room before storage in CA cabinets of Fruit Control Equipments (model Venezia PCM 1.000, Milan, Italy). Based on previous results obtained for the storage of 'Palmer' mangoes under CA (Teixeira and Durigan, 2011; Teixeira *et al.*, 2018), the fruit were stored in atmospheres containing 5 kPa O_2 + 5 kPa CO_2 for 30 d at 14.2 ± 2.3 °C and 92.6 ± 2.8% RH. The levels of oxygen (O_2) and carbon dioxide (CO_2) were maintained using nitrogen (White Martins Gases Industriais Ltda., Brazil) and CO_2 (Conservare®, White Martins Gases Industriais Ltda., Brazil) injections, which were controlled by the software Swinglos® (Fruit Control Equipments, Milan, Italy). Ethylene (C_2H_4) levels were maintained close to 0.0 kPa using a potassium permanganate absorber also controlled by the software Swinglos®. After 30 d of storage under CA the mangoes were transferred to ambient conditions (23.7 ± 1.1 °C and 73.4 ± 15.1% RH) for four days to simulate commercialization.

The experiment was set up as a completely randomized design (CRD) in a factorial arrangement 2 × 2. The first factor was the sorting method (visual and sorting based on 150 g kg^{-1} DM) and the second factor the storage period (0, and 30 d CA storage), with 10 replications of one mango (experimental unit). After the fruit were transferred to room temperature a CRD with 2 treatments (visual sorting and 150 g kg^{-1} DM) and 10 replications of one mango (replicate) was followed.

Evaluation of the fruit quality

Fruit quality was evaluated at harvest (day 0), after 30 d of CA storage (day 30), and after 30 d plus 4 d at ambient conditions, as follows:

Fruit weight loss. Fruit weight loss (FWL) was determined based on the difference in the fruit mass at different time points (0 d, 30 d in CA storage, and 30 d plus 4 d at ambient conditions). The fruit mass was determined using a semi-analytical balance with a precision of 0.01 g (Marte, model AS 2000, São Paulo, Brazil).

Color. Skin color was determined using a Minolta colorimeter (Model CR-400, Minolta Corp., Osaka, Japan) with an 8 mm aperture. The L*, a*, b* color parameters were used to obtain lightness (L*), chroma (C*) and hue angle (McGuire, 1992). Two readings were taken from each fruit on opposite sides of the equatorial region.

Firmness. Firmness of the mango flesh was determined on opposite sides on the equatorial region of each fruit after removing the skin, according to Watkins and Harman (1981). An Effegi Fruit Tester penetrometer (Bishop FT 327 Penetrometer, Alfonsine, Italy) with an 8.0 mm tip was used and the results were expressed in newton (N).

Physico-chemical analysis. In each repetition, fruit flesh without skin was homogenized, juiced, and used to determine soluble solids content (SSC) using a digital refractometer PR-101α (Atago, Tokyo, Japan) according to the AOAC method 920.151 (AOAC, 1997). Titratable acidity (TA) was determined using AOAC method 932-12 (AOAC, 1997). The SSC/TA ratio was obtained, and the pH was determined (AOAC, 1997-proc 945-27). Vitamin C content was determined using Tillmans method (Strohecker and Henning, 1967).

Statistical analysis

Analysis of variance (ANOVA) was performed with the obtained data using Statistica (Release 4.5, StatSoft, Inc., EUA) and the means were compared using Tukey's test at the $\alpha = 0.05$.

Results and discussion

Prediction of the DM using portable Vis-NIR

The PLSR model used to predict the DM content of the first 43 mangoes had an $RMSE_C$ of 10.1 g kg^{-1}, $RMSE_{cv}$ of 10.5 g kg^{-1}, R^2_c of 0.77, and R^2_P of 0.75. Using this model to predict the DM content of mangoes produced in Petrolina, PE without pre-processing the Vis-NIR spectra, the $RMSE_P$ values increased to 20.2 g kg^{-1} and the R^2 reduced to 0.19 (Figure 1). The decline in the performance was due to the differences in the fruit batches, as the model developed by Santos Neto *et al.* (2018) was built only with 'Palmer' mangoes produced in Cândido Rodrigues, SP. Differences related to fruit batches are crucial factors in NIRS, as fruit have a large variation. In addition, seasonal variability and maturity stages also affect the performance of NIRS model (Peirs *et al.*, 2002).

To reduce the $RMSE_P$ value, the Vis-NIR spectra of 43 fruit harvested in Petrolina, PE were incorporated into the calibration set obtained in 2015/2016 and 2016/2017 and a new PLSR model was developed (Figure 2). By incorporating the Vis-NIR spectra the values of $RMSE_C$ reduced to 12.2 g kg^{-1}, the $RMSE_{cv}$ to 13.8 g kg^{-1}, and the R^2_c increased to 0.70 (Figure 2). Although slightly inferior to the PLSR model re-

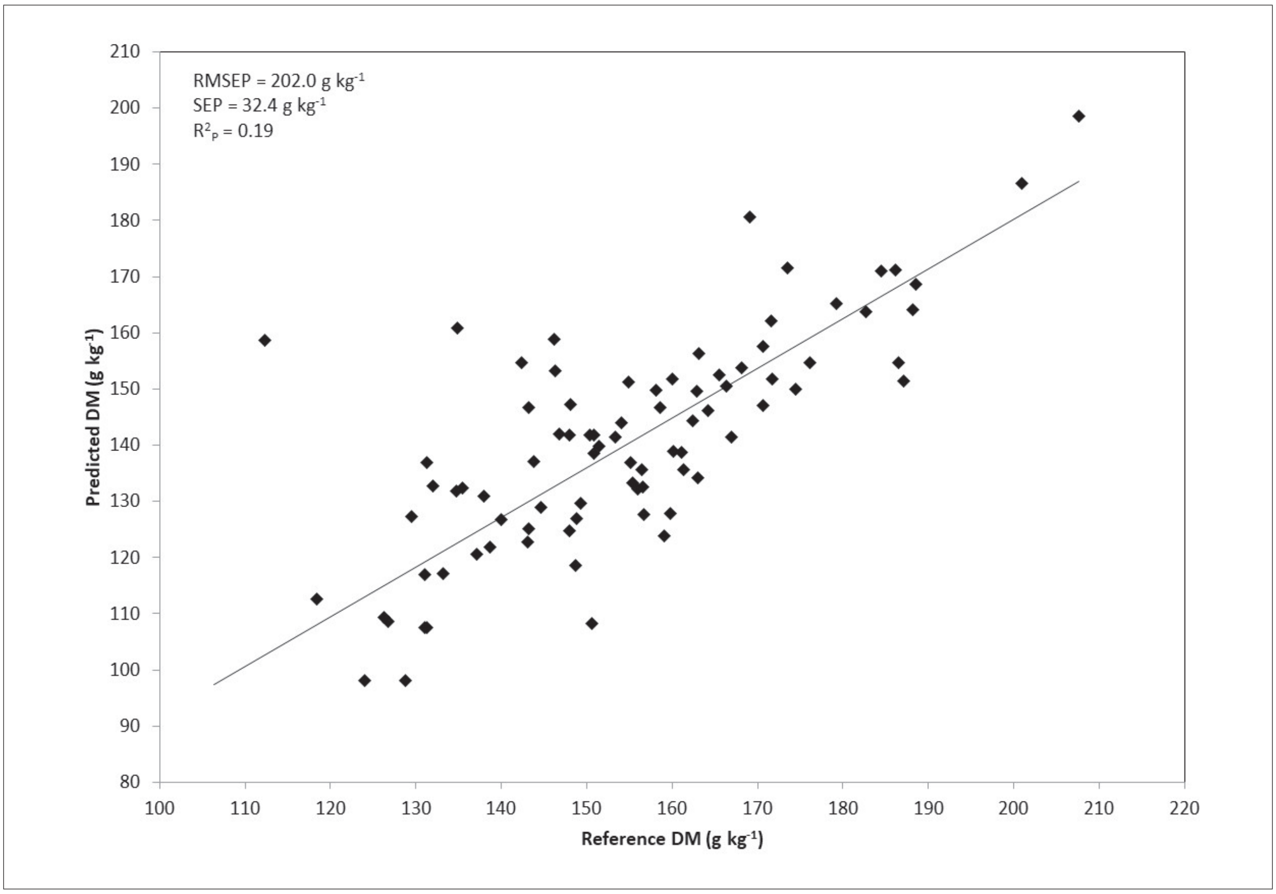

FIGURE 1. Dry matter (DM) content of 'Palmer' mangoes harvested in Petrolina, PE, predicted using the PLSR model developed by Santos Neto *et al.* (2018).

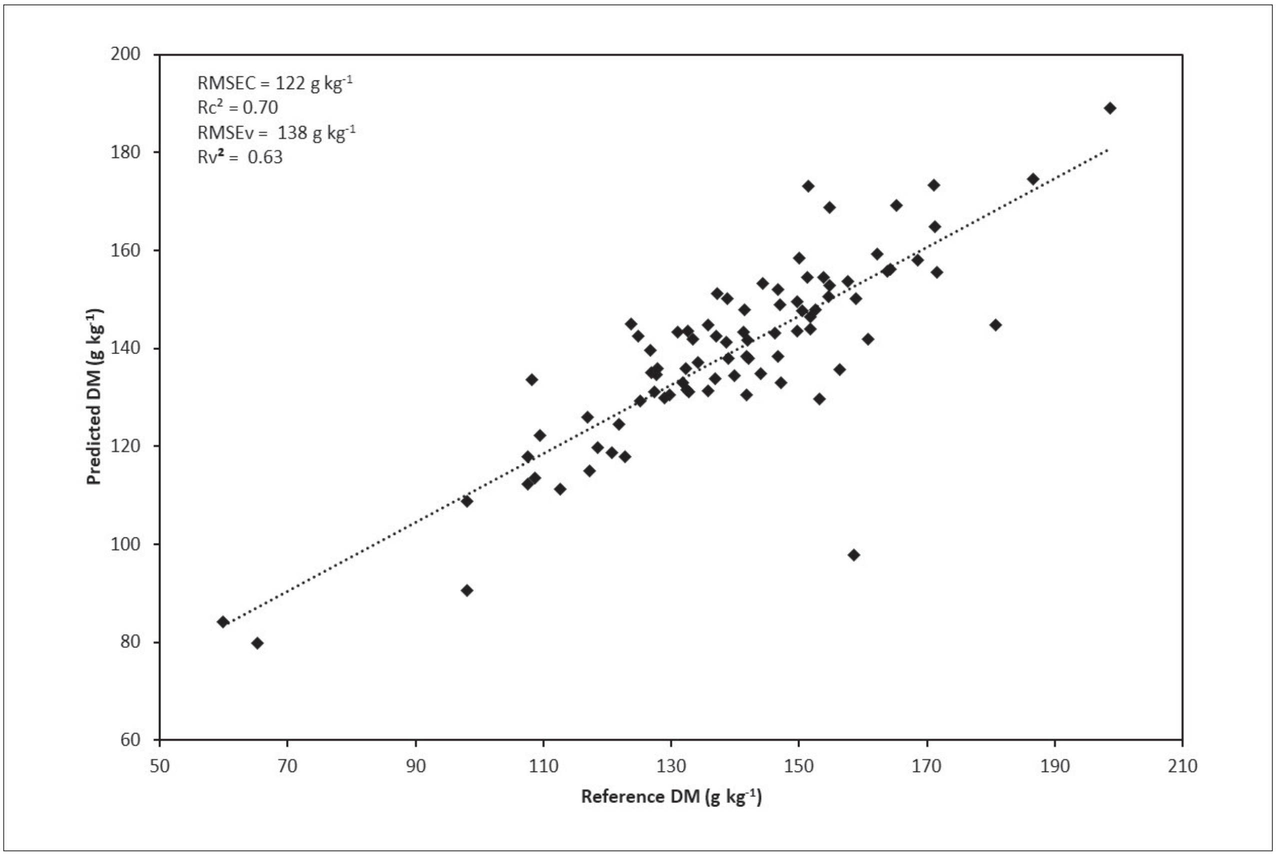

FIGURE 2. Estimated and predicted dry matter (DM) content of 'Palmer' mangoes harvested in Petrolina, PE.

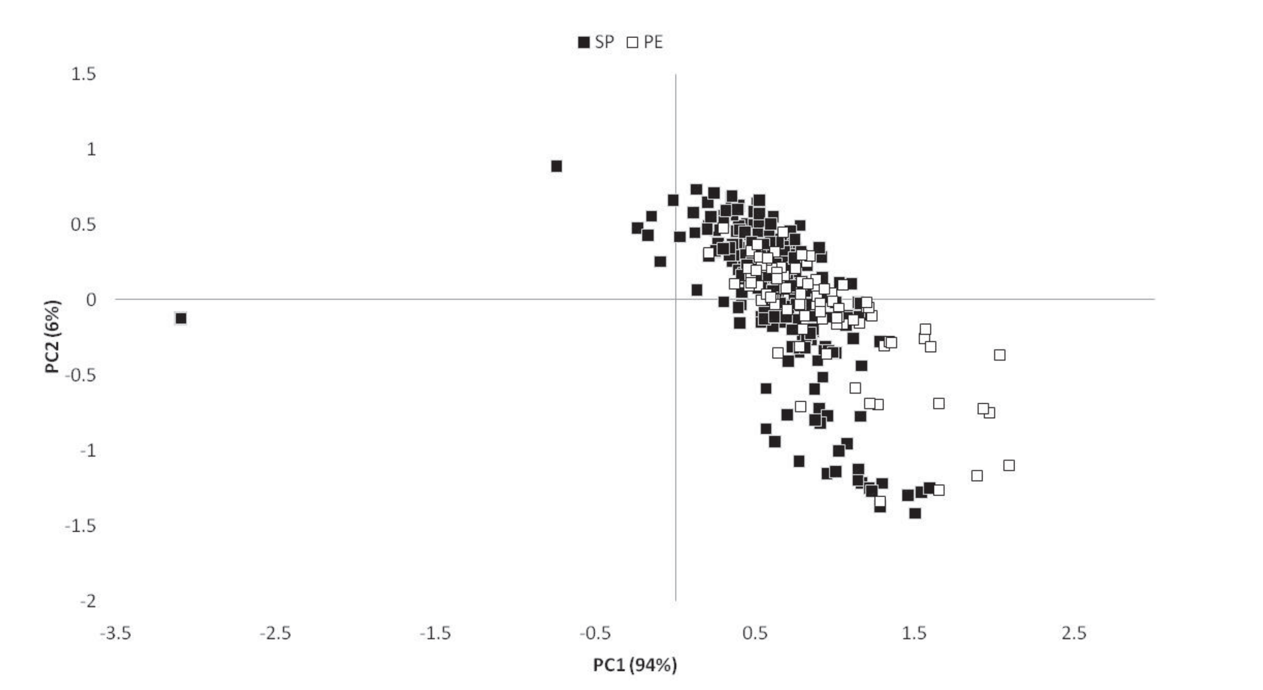

FIGURE 3. Scores of principal component 1 (PC1) and 2 (PC2) obtained with raw NIR spectra (699–981 nm) of 'Palmer' mangoes harvested in Cândido Rodrigues, SP (2015/16 and 2016/17 seasons – SP) and in Petrolina, PE (PE).

ported by Santos Neto *et al.* (2018), the new model was more robust, as it incorporated a new source of variability coming from the mangoes produced in Petrolina, PE.

To sort the mangoes based on DM, the value of 150 g kg^{-1} DM content plus or minus the new $RMSE_V$ value of 13.8 g kg^{-1} was used. Thus, the fruit with DM in the range of 136.2 g kg^{-1} to 163.8 g kg^{-1} were sorted as belonging to the 150 g kg^{-1} DM treatment. It is important to note that when the mangoes were sorted based on the DM content of 150 g kg^{-1}, only 29.05% of the fruit were classified into this category, whereas the remaining 70.97% were disposed. On the other hand, for the traditional handling no fruit was disposed. As reported by Santos Neto *et al.* (2018), this result highlights the importance of the use of portable Vis-NIR to sort mangoes in the field, as only high-quality fruit would be harvested, packed, transported, and offered to consumers.

Principal component analysis (PCA) was carried out to assess the difference between the mangoes produced in Petrolina, PE in relation to Cândido Rodrigues, SP (Figure 3). The principal component 1 and 2 (PC1 and PC2) accounted for 100% of the explained variance, wherein 94% was explained by PC1 and 6% by PC2 (Figure 3). The Vis-NIR spectra of mangoes produced in Petrolina, PE clustered in the right quadrant of the PC1 with those harvested in Cândido Rodrigues, SP (2015/2016 and 2016/2017), without clear segregation between clusters. Although Peirs *et al.* (2002) indicated that the NIRS is greatly influenced by the differences within fruit batches, there was no segregation between 'Palmer' mangoes produced in different regions. On the other hand, Santos Neto *et al.* (2018) reported segregation of 'Palmer' mangoes harvested in different seasons. Discriminant analysis should be performed as NIRS allows the identification of the origin of the fruit and can be used to identify the geographical indication (GI) of the fruit, making discrimination of batches possible, as reported in other fruit (Cunha Júnior *et al.*, 2015).

CA storage

Fruit weight loss

The fruit weight loss (FWL) of the 'Palmer' mangoes is given in the Figure 4. No significant differences in FWL were observed between the fruit sorted based on 150 g kg^{-1} DM and fruit sorted based on visual appearance (Figure 4). The duration of storage period affected FWL (Figure 4). At the end of the CA storage (30 d) the FWL reached a maximum of 0.98–0.90% in the fruit from both treatments. Therefore, the relative humidity (RH) within the CA chambers (92.6 ± 2.8%) adequately controlled the dehydration as the RH stayed within the limit (90–95%) recommended for fruit storage (Kader, 2003). Similar results were reported by Teixeira and Durigan (2011), who observed a maximum FWL of 0.74% when 'Palmer' mangoes were stored under CA with different O_2 concentrations (21, 15, 10, 5, and 1.0 kPa O_2) for 28 d at 12.8 °C. Similarly, Teixeira *et al.* (2018) reported FWL of only 1.04% in 'Palmer' mangoes stored under CA in atmospheres containing 5 kPa O_2 plus 1.0, 5, 10, 15, and 20 kPa CO_2 for 30 d at 12.8 °C.

On the other hand, when mangoes were transferred to ambient conditions (23.7 ± 1.1 °C and 73.4 ± 15.1% RH) FWL reached 3.12–3.52% in just 4 d independent of treatment (Figure 4).

Fruit quality

Physico-chemical characteristics of the 'Palmer' mangoes sorted with 150 g kg^{-1} DM and visual appearance stored under CA for 30 d are presented in Table 2. During CA storage, no significant differences in fruit color were observed between mangoes from both treatments, but color was affected by the storage period with a decrease in L* (Table 2). The other color parameters did not change, and mangoes presented colors with low chroma (C* = 10.44–10.51) and purple hue (h = 229.65–241.16 °). The low storage temperature during CA contributed to the minimal modification in color. O'Hare

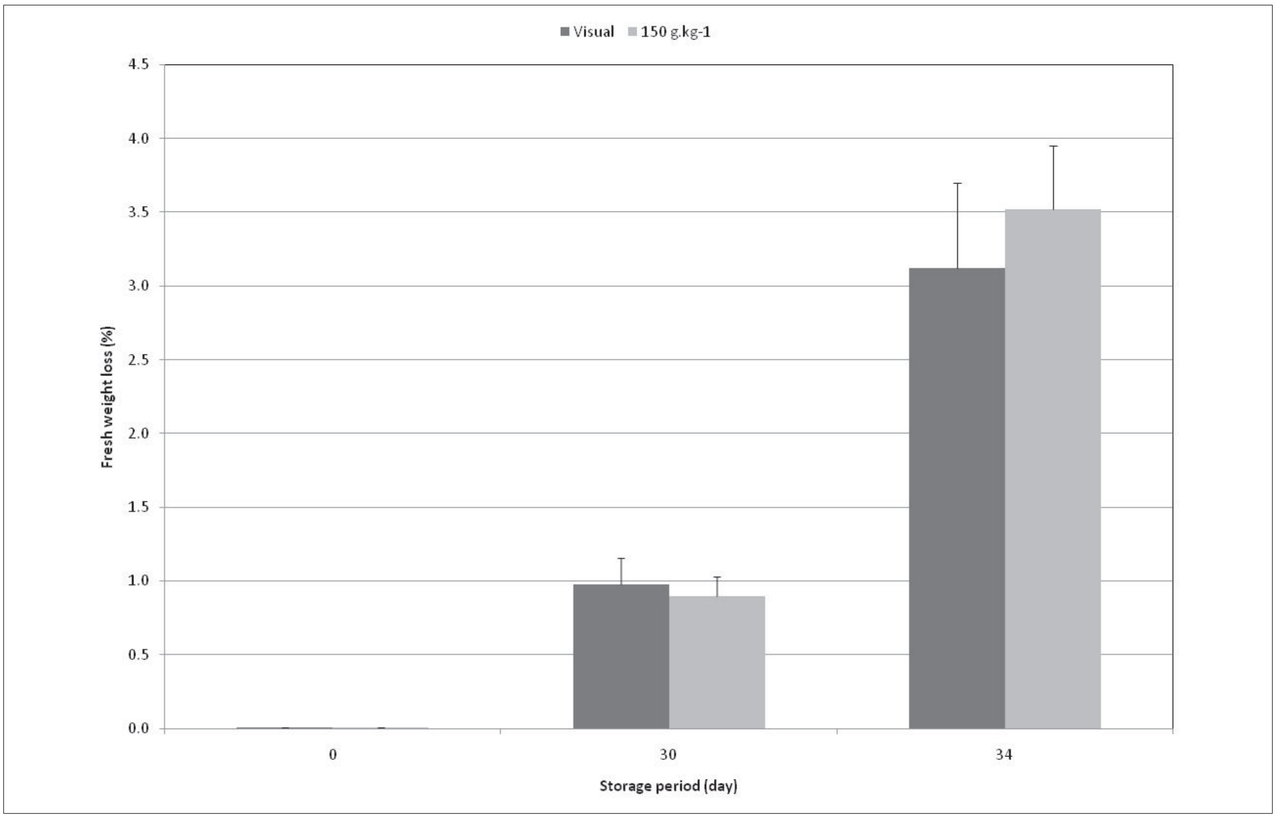

FIGURE 4. Fresh weight loss (FWL) of 'Palmer' mangoes sorted based on visual characteristics and with 150 g kg^{-1} DM content using a portable visible near-infrared (Vis-NIR) stored under controlled atmosphere (CA) with (5 kPa O_2 + 5 kPa CO_2) for 30 d at 14.2 ± 2.3 °C and 92.6 ± 2.8% RH, and 4 d at ambient (23.7 ± 1.1 °C and 73.4 ± 15.1% RH). The vertical bars indicate standard deviations of 10 replicates.

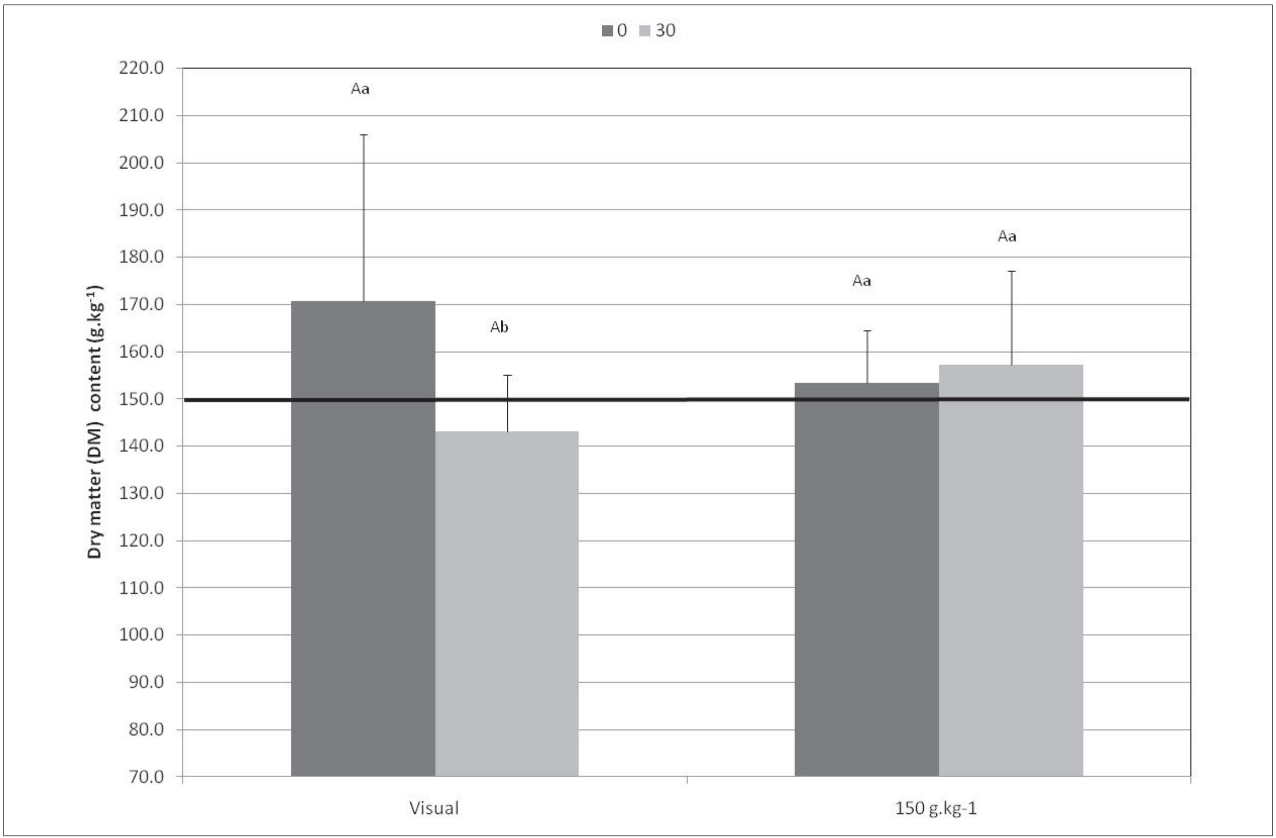

FIGURE 5. Dry matter (DM) content (g kg^{-1}) of 'Palmer' mangoes harvested in Petrolina, PE, and sorted based on visual stored under controlled atmosphere (CA) conditions (5 kPa O_2 + 5 kPa CO_2) at 14.2 °C for 30 d. The vertical bars indicate standard deviations of 10 replicates.

Table 2. Physico-chemical parameters of 'Palmer' mangoes sorted based on visual characteristics and with 150 g kg^{-1} DM content using a portable visible near-infrared (Vis-NIR) stored under controlled atmosphere (CA) with (5 kPa O_2 + 5 kPa CO_2) for 30 d at 14.2±2.3 °C and 92.6±2.8% RH.

Sources of variation	L*[1]	a[2]	b[2]	h°[3]	C*[4]	pH[5]	SSC (%)[6]	TA[7]	Ratio (SSC/TA)[8]	Vit. C (g kg^{-1})[9]	Firmness (N)	DM (g kg^{-1})[10]
Treatments (T)												
Visual sorting	34.87	-3.62	10.44	229.65	11.71	2.85	10.78	0.42	26.26	0.28	24.04	157.0
150 g kg^{-1} DM	33.78	-3.40	10.51	241.16	11.98	2.96	10.92	0.39	29.67	0.32	23.19	155.3
F test	0.7013	0.8154	0.8940	0.3369	0.6773	0.6187	0.9002	0.5242	0.4125	0.4348	0.5738	0.8288
Storage (S)												
0	35.69 a	-3.28	10.41	238.84	11.98	2.26 b	6.64 b	0.33 b	20.48 b	0.21 b	32.91 a	162.1
30	33.79 b	-3.74	10.55	231.92	11.71	3.55 a	10.78 a	0.49 a	35.45 a	0.40 a	14.32 b	150.2
F test	0.0059*	0.6225	0.8029	0.5683	0.6817	0.001**	0.0001**	0.0005**	0.0002**	0.0001***	0.0001***	0.1080
Interaction												
T × S	0.0651	0.1862	0.0185	0.5251	0.0583	0.0162	0.1440	0.4452	0.0788	0.9444	0.5874	0.0276*

[1]Lightness (L). [2]a*, b* coordinates; [3]Hue angle; [4]chromaticity; [5]hydrogenionic potential; [6]soluble solids content; [7]titratable acidity; [8]Ratio (SSC/TA); [9]ascorbic acid content; [10]dry matter content. Average values with the same letter within the columns are not statistically different by Tukey's test ($p < 0.05$). Values in the column without letter are not statistically different by Tukey's test ($p < 0.05$). * Indicates $p < 0.05$. ** Indicates $p < 0.01$. *** Indicates $p < 0.001$ by Tukey's test. NS - not significant.

Table 3. Physico-chemical parameters of 'Palmer' mangoes sorted based on visual characteristics and with 150 g kg^{-1} DM content using a portable visible near-infrared (Vis-NIR) stored under controlled atmosphere (CA) with (5 kPa O_2 + 5 kPa CO_2) for 30 d at 14.2 ± 2.3 °C and 92.6 ± 2.8% RH, and 4 d at ambient (23.7 ± 1.1 °C and 73.4 ± 15.1% RH).

Sources of variation	L*[1]	a*[2]	b*[2]	h°[3]	C*[4]	pH[5]	SSC (%)[6]	TA[7]	Ratio (SSC/TA)[8]	Vit. C (g kg^{-1})[9]	Firmness (N)	DM (g kg^{-1})[10]
Visual sorting	37.65	0.81	13.03	281.93	13.87	4.54	15.07	0.27	57.70	0.33	1.72	143.2
150 g kg^{-1} DM	37.83	-1.08	13.72	255.24	14.11	4.66	15.88	0.26	61.66	0.29	2.01	150.4
F test	0.9121	0.1529	0.6351	0.0382	0.8750	0.4021	0.4001	0.5040	1.000	0.4823	0.4021	0.5082

[1]Lightness (L). [2]a*, b* coordinates; [3]Hue angle; [4]chromaticity; [5]hydrogenionic potential; [6]soluble solids content; [7]titratable acidity; [8]Ratio (SSC/TA); [9]ascorbic acid content; [10]dry matter content. Average values with the same letter within the columns are not statistically different by Tukey's test ($p < 0.05$). Values in the column without letter are not statistically different by Tukey's test ($p < 0.05$).

(1995) reported that 'Kensington Pride' mangoes stored at 13 °C did not reach the characteristic color of this cultivar. Carotenoid synthesis in mango is reduced during cold storage (Medlicott *et al.*, 1986). In addition, when cold storage is associated with CA storage, mainly in low O_2 (5.0 kPa O_2), color and firmness modifications are more impaired as these processes require ethylene to be triggered (Kader, 1995). According to Kader (1995), in atmospheres with O_2 concentrations lower than 8.0 kPa there is a reduction in the ethylene production through the inhibition of the 1-aminocyclopropane-1-carboxylic acid (ACC) synthesis, as well as, the ACC oxidase. Therefore, the use of CA with 5.0 kPa O_2 + 5.0 kPa CO_2 allows the maintenance of the 'Palmer' mango quality similar to previously reported by Teixeira and Durigan (2011), and Teixeira *et al.* (2018).

No significant differences were observed in the other physico-chemical parameters between mangoes from both treatments, but storage period affected SSC, pH, TA, ratio (SST/TA), vitamin C content, and firmness (Table 2). It should be noted that the mangoes from both treatments presented initial SSC of 6.64% and the SSC increased to 10.78% after 30 d under CA storage (Table 2). Fruit firmness decreased from 32.91 N to 14.32 N (Table 2), indicating that mangoes were riper after 30 d under CA storage. Teixeira and Durigan (2011) and Teixeira *et al.* (2018) reported that 'Palmer' mangoes, when stored under CA for 28 or 30 d, also presented modifications in SSC and firmness, yet to a lesser extent when stored in low O_2 (1.0–10 kPa). The modifications in SSC and firmness are dependent on the action of ethylene as this hormone initiates the ripening process and consequently the expression of several enzymes related to cell wall disassembly (Kader, 1995).

A significant interaction ($p < 0.0276$) was observed between treatments (visual and 150 g kg^{-1} sorted mangoes) at the end of storage period, but the only significant difference was the lower DM content of visually sorted mangoes after 30 d of CA storage (Table 2, Figure 5). This might be attributed to the lack of uniformity in visually sorted mangoes. These results highlight that it was possible to sort the mangoes according to the desired maturity stage, approaching the recommended DM content of 150 g kg^{-1} (Walsh, 2016), using NIRS. However, the DM content of mangoes sorted based on 150 g kg^{-1} method were not significantly different from that of the fruit sorted via the traditional method based on the visual appearance (Table 2, Figure 5). As the fruit were harvested late in the season, more mature mangoes were harvested, which justifies the lack of the effect of treatments on the average DM content, similar to the findings of Anderson *et al.* (2017) in Australia. Although not much differences were observed, the standard deviation (SD) for the fruit sorted by the traditional handling was higher (23.3 g kg^{-1}) than for the fruit sorted with 150 g kg^{-1} DM (15.9 g kg^{-1}). As there are complaints about the lack of uniformity in mango consignments, particularly regarding stages of maturity, the use of NIRS allows a more uniform fruit sorting process.

Even with the modification in SSC and loss of firmness of the fruit flesh after 30 d of storage under CA, the mangoes were not completely ripe and presented a similar quality to recently harvested fruit.

Fruit quality under ambient conditions following storage

No significant differences were observed between the mangoes sorted based on 150 g kg^{-1} DM and based on visual appearance, and the fruit ripened normally without evidence of physiological disorders (Table 3). The fruit presented the typical 'Palmer' mango color with dark (L* = 37.65–37.83) purple peel (hue angle = 255.24–281.93 °). Rapid softening occurred after removal from storage to ambient conditions and mangoes were considered to be ripened after 4 d in these conditions. Jeronimo and Kanesiro (2000) also reported an increase in the rate of the ripening process when 'Palmer' mangoes were transferred to ambient conditions after cold storage. Similarly, Teixeira and Durigan (2011) and Teixeira *et al.* (2018) reported that 'Palmer' mangoes previously stored under CA ripen faster after they are transferred to ambient conditions. Although no physiological disorders were observed, an increase in the decay caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc, which was absent during CA storage, was observed at ambient temperature.

Conclusion

During CA storage of 'Palmer' mangoes sorted based on visual characteristics and based on 150 g kg^{-1} DM content using a portable near-infrared (Vis-NIR) spectrometer presented similar postharvest patterns. The main advantage of using NIRS to sort mangoes with 150 g kg^{-1} DM was to achieve a more homogeneous fruit batch with lower standard deviation in comparison to that of visually sorted fruit. The use of portable near-infrared (NIR) spectrometer allows sorting more uniform fruit based on a pre-determined DM content, which improves the quality of the mangoes to be exported.

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References

Abbott, J.A. (1999). Quality measurement of fruits and vegetables. Postharv. Biol. Technol. *15*, 207–225. https://doi.org/10.1016/S0925-5214(98)00086-6.

Anderson, N.T., Subedi, P.P., and Walsh, K.B. (2017). Manipulation of mango fruit dry matter content to improve eating quality. Sci. Hortic. *226*, 316–321. https://doi.org/10.1016/j.scienta.2017.09.001.

Association of Official Analytical Chemists (AOAC) (1997). Official Methods of Analysis of the Association of Official Analytical Chemists, 16th ed. (Arlington: Ed. Patrícia Cuniff).

Bender, R.J., Brecht, J.K., and Sargent, S.A. (2000). Mango tolerance to reduced oxygen levels in controlled atmosphere storage. J. Am. Soc. Hortic. Sci. *125*, 707–713. https://doi.org/10.21273/JASHS.125.6.707.

Brecht, J.K., Chau, K.V., Fonseca, S.C., Oliveira, F.A.R., Silva, F.M., Nunes, M.C.N., and Bender, R.J. (2003). Maintaining optimal atmosphere conditions for fruits and vegetables throughout the postharvest handling chain. Postharv. Biol. Technol. *27*, 87–101. https://doi.org/10.1016/S0925-5214(02)00185-0.

Cunha Júnior, L.C., Nardini, V., Khatiwada, B.P., Teixeira, G.H.A., and Walsh, K.B. (2015). Classification of intact açaí (*Euterpe oleracea* Mart.) and juçara (*Euterpe edulis* Mart.) fruits based on dry matter content by means of near infrared spectroscopy. Food Control *50*, 630–636. https://doi.org/10.1016/j.foodcont.2014.09.046.

Instituto Brasileiro de Geografia e Estatística (IBGE) (2015). Levantamento sistemático da produção agrícola. 2009 e 2010. http://www.ibge.gov.br. (accessed September 16, 2015).

Jeronimo, E.M., and Kanesiro, M.A.B. (2000). Efeito da associação de armazenamento sob refrigeração e atmosfera modificada na qualidade de mangas 'Palmer'. Rev. Bras. Frutic. *22*, 237–243.

Kader, A.A. (1986). Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Chemistry *40*, 99–100.

Kader, A.A. (1995). Regulation of fruit physiology by controlled/modified atmospheres. Acta Hortic. *398*, 59–70. https://doi.org/10.17660/ActaHortic.1995.398.6.

Kader, A.A. (2003a). Postharvest biology and technology: an overview. In Postharvest Technology of Horticultural Crops, A.A. Kader, ed. (Davis: University of California, Division of Agriculture and Natural Resources Publication), p. 39–47.

Kader, A.A. (2003b). A summary of CA requirements and recommendations for fruits other than apples and pears. Acta Hortic. *600*, 737–740. https://doi.org/10.17660/ActaHortic.2003.600.112.

Lizada, M.C.C., Biglete-Flor, N.A., and Garcia, N.L. (2004). The response of the 'Carabao' mango to controlled atmospheres. 5th International Postharvest Symposium, Volume of Abstracts (Verona, Italy).

McGuire, R.G. (1992). Reporting of objective color measurements. HortScience *27*, 254–255. https://doi.org/10.21273/HORTSCI.27.12.1254.

McLauchan, R.L., and Barker, L.R. (1992). Controlled atmospheres for Kensington mango storage: classical atmospheres. Development of Postharvest Handling Technology for Tropical Tree Fruits, Canberra (Canberra, Australia).

Medlicott, A.P., Reynolds, S.P., and Thompson, A.K. (1986). Effects of temperature on the ripening of mango fruit (*Mangifera indica* L. var. Tommy Atkins). J. Sci. Food Agric. *37*, 469–474. https://doi.org/10.1002/jsfa.2740370506.

Ministério da Agricultura, Pecuária e Abastecimento (MAPA) (2016). AGROSTAT – Estatisticas de Comércio Exterior do Agronegócio Brasileiro. http://indicadores.agricultura.gov.br/agrostat/index.htm (accessed December 15, 2017).

Mitra, S.K. (2016). Mango production in the world – present situation and future prospect. Acta Hortic. *1111*, 287–296. https://doi.org/10.17660/ActaHortic.2016.1111.41.

Mitra, S.K., and Baldwin, E.A. (1997). Mango. In Postharvest Physiology and Storage of Tropical and Subtropical Fruit, S.K. Mitra, ed. (Wallingford: CAB International), p. 85–122.

Neto, Á.G., Gayet, J.P., Bleinroth, E.W., Matallo, M., Garcia, A.E., Ardito, E.F.C., Garcia, E.E.C., and Bordin, M.R. (1994). Manga para exportação: procedimentos de colheita e pós-colheita. Série Publicações Técnicas FRUPEX, No. 4 (Brasília: EMBRAPA-SPI).

Nicolaï, B.M., Beullens, K., Bobelyn, E., Peirs, A., Saeys, W., Theron, K.I., and Lammertyn, A.J. (2007). Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: A review. Postharv. Biol. Technol. *46*, 99–118. https://doi.org/10.1016/j.postharvbio.2007.06.024.

O'Hare, T.J. (1995). Effect of ripening temperature on quality and composition changes of mango (*Mangifera indica* L.) cv. Kensington. Austral. J. Exper. Agric. *35*, 259–263. https://doi.org/10.1071/EA9950259.

Owen, G., and Moore, C. (2013). Mango dry matter instructions. Information sheet. https://nt.gov.au/_data/assets/pdf_file/0004/267709/mango-dry-matter-instructions-information-sheet.pdf. (accessed February 4, 2018).

Peirs, A., Tirry, J., Verlinden, B., Darius, P., and Nicolaï, B.M. (2002). Effect of biological variability on the robustness of NIR-models for soluble solids content of apples. Postharv. Biol. Technol. *28*, 269–280. https://doi.org/10.1016/S0925-5214(02)00196-5.

Santos Neto, J.P., Assis, M.W.D., Casagrande, I.P., Cunha Júnior, L.C., and Teixeira, G.H.A. (2017). Determination of 'Palmer' mango maturity indices using portable near infrared (VIS-NIR) spectrometer. Postharv. Biol. Technol. *130*, 75–80. https://doi.org/10.1016/j.postharvbio.2017.03.009.

Santos Neto, J.P., Leite, G.W.P., Oliveira, G.S., Cunha Júnior, L.C., Gratão, P.L., and Teixeira, G.H.A. (2018). Cold storage of 'Palmer' mangoes sorted based on dry matter content using portable near infrared (VIS-NIR) spectrometer. J. Food Process. Pres. *42*, e13644-11. https://doi.org/10.1111/jfpp.13644.

Singh, Z., and Zaharah, S.S. (2015). Controlled atmosphere storage of mango fruit: challenges and thrusts and its implications in international mango trade. Acta Hortic. *1066*, 179–192. https://doi.org/10.17660/ActaHortic.2015.1066.21.

Strohecker, R., and Henning, H.M. (1967). Análises de Vitaminas: Métodos Comprovados. (Madrid: Paz Montolvo).

Teixeira, G.H.A., and Durigan, J.F. (2011). Storage of 'Palmer' mangoes in low-oxygen atmospheres. Fruits *66*, 279–289. https://doi.org/10.1051/fruits/2011037.

Teixeira, G.H.A., Santos, L.O., Cunha Júnior, L.C., and Durigan, J.F. (2018). Increasing levels of carbon dioxide (CO_2) associated with low-oxygen (O_2) do not affect the quality of 'Palmer' mangoes during controlled atmosphere storage. Food Sci. and Technol. *55*, 145–156. https://doi.org/10.1007/s13197-017-2873-4.

Trinidad, M., Bósquez, E., Escalona, H., Días De León, F., Pérez Flores, L., Kerbel, C., Ponce De León, L., Muñoz, C., and Pérez, L. (1997). Controlled atmosphere (5% CO_2 - 5% O_2 and 10% CO_2 - 5% O_2) do not significantly increase the shelf life of refrigerated Kent mangoes. Acta Hortic. *455*, 643–653. https://doi.org/10.17660/ActaHortic.1997.455.83.

Walsh, K.B. (2016). Dry matter matters. http://www.industry.mangoes.net.au/resource-collection/2016/3/6/dry-matter-matters (accessed March 25, 2017).

Walsh, K.B., and Subedi, P.P. (2016). In-field monitoring of mango fruit dry matter for maturity estimation. Acta Hortic. *1119*, 273–278. https://doi.org/10.17660/ActaHortic.2016.1119.38.

Watkins, C., and Harman, J. (1981). Use of penetrometer to measure flesh firmness of fruit. Orchardist New Zealand *54*, 14–16.

Whiley, A.W., Hofman, P.J., Christiansen, H., Marques, R., Stubbings, B., and Whiley, D.G. (2006). Horticulture Australia development of pre- and postharvest protocols for production of Calypso mango (Sydney: Horticultural Australia).

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