ISSN 0100-2945
DOI: http://dx.doi.org /10.1590/0100-29452021014

Revista Brasileira de Fruticultura

Harvest and post harvest

Sample size for postharvest quality traits of 'Palmer' mangoes

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Abstract - The objective of this study was to determine the most efficient sample size required to estimate the mean of postharvest quality traits of 'Palmer' mangoes harvested in two growing seasons. A total of 50 mangoes were harvested at maturity stage 2, in winter (June 2020) and spring (October 2020), and evaluated for weight, length, ventral and transverse diameter, skin and pulp L^*, C^* and h^o, dry matter, firmness, soluble solids (SS), titratable acidity (TA) and the SS/TA ratio. According to the results, the coefficient of variation (CV) of fruit quality traits ranged from 2.1% to 18.1%. The highest CV in both harvests was observed for the SS/TA ratio, while the lowest was reported for pulp h^o. In order to estimate the mean of physicochemical traits of 'Palmer' mangoes, 12 fruits are needed in the winter and 14 in the spring, considering an estimation error of 10% and a confidence interval of 95%. TA and the SS/TA ratio required the highest sample size, while L^* and h^o required the lowest sample size. In conclusion, the variability was different among physicochemical traits and seasons, implying that different sample sizes are required to estimate the mean of different quality traits in different growing seasons.
Index terms: *Mangifera indica* L., sampling, experimental planning, post-harvest.

Dimensionamento amostral para caracteres de qualidade pós-colheita de mangas 'Palmer'

Resumo - O objetivo deste estudo foi determinar o tamanho da amostra mais eficiente necessário para estimar a média dos caracteres de qualidade pós-colheita de mangas 'Palmer' colhidas em duas estações. Cinquenta mangas foram coletadas no estágio de maturação 2, no inverno (junho de 2020) e na primavera (outubro de 2020), e avaliadas quanto à massa, comprimento, diâmetros ventral e transversal, L^*, C^* e h^o de casca e de polpa, matéria seca, firmeza, sólidos solúveis (SS), acidez titulável (AT) e relação SS/AT. De acordo com os resultados, o coeficiente de variação (CV) dos caracteres de qualidade dos frutos variou de 2,1 a 18,1%. O maior CV, em ambas as safras, foi observado para a relação SS/AT, enquanto o menor foi reportado para h^o da polpa. Para estimar a média dos caracteres físico-químicos de mangas 'Palmer', são necessários 12 frutos na colheita de inverno e 14 da primavera, considerando um erro de estimativa de 10% e um intervalo de confiança de 95%. A AT e a relação SS/AT exigiram o maior tamanho de amostra, enquanto L^* e h^o exigiram o menor tamanho de amostra. Conclui-se que a variabilidade foi diferente entre os caracteres físico-químicas e as estações, implicando que diferentes tamanhos de amostra são necessários para estimar a média de diferentes caracteres de qualidade em diferentes estações.
Termos para indexação: *Mangifera indica* L., amostragem, planejamento experimental, pós-colheita.

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Received: March 04, 2021
Accepted: June 21, 2021

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Introduction

Mango (*Mangifera indica* L.), also known as 'the king of fruits', is the second most produced and consumed tropical fruit around the world due to unique features such as its delicate and tropical taste, pleasant aroma and nutritional composition (SINGH et al., 2013; FAO, 2019).

The most often used traits to determined mango quality are weight, diameter, skin and pulp colour, texture, dry matter, soluble solids content and acidity (ANDERSON et al., 2017; NORDEY et al., 2016; NTSOANE et al., 2019). Harvest maturity is known to play an important role in determining postharvest fruit life and fruit quality. As a climacteric fruit, mango is harvested at physiological maturity, completing the ripening process during shipping to the final market (BRECHT; YAHIA, 2017).

In postharvest studies, determining the most efficient sample size is important to guarantee that each sample will effectively represent the whole fruit batch. In addition, determining the ideal sample size will optimize the time, labour and expenses required for sample analyses (ARELLANO-DURÁN et al., 2018; CARGNELUTTI FILHO et al., 2018). In that case, determination of the most efficient sample size improves the efficiency of the research, allowing different fruit traits to be analysed with the desired precision. The data variability and the desired reliability in the mean estimation are directly proportional to the sample size, while the estimation error allowed is inversely proportional (BUSSAB; MORETTIN, 2017). Therefore, the higher the variation and/or desired precision, the higher will be the sample size.

Previous studies have been conducted to determine the most efficient sample size for several fruit species, including peach (TOEBE et al., 2011), apple (TOEBE et al., 2014), passion fruit (BANDEIRA et al., 2016; COELHO et al., 2011; SCHMILDT et al., 2017a), pecan (CARGNELUTTI FILHO et al., 2015; POLETTO et al., 2018), red mombin (SILVA et al., 2016) and papaya (SCHMILDT et al., 2019). In mango, a previous study determined the most efficient sample size for quantitative traits in the seeds of polyembryonic cultivars (ARELLANO-DURÁN et al., 2018; VILLEGAS-MONTER; MUÑOZ-OROZCO, 2018). However, no reports were found in the literature about the most efficient sample size for physicochemical quality analyses of mango.

The objective of this study was to determine the most efficient sample size required to estimate the mean of postharvest quality traits of 'Palmer' mangoes harvested in two growing seasons.

Material and methods

The experiment was carried out with 'Palmer' mango (*Mangifera indica* L.) cultivated in a commercial orchard in Petrolina, PE, Brazil (09°09′S, 40°22′W and 365 m above sea level). According to Köppen's classification, the region has a Semi-arid climate (Bswh) with average annual temperature of 26°C, rainfall of 500 mm, and relative humidity of 66%. The fruit were produced during two different growing seasons and harvested in the winter (June 16, 2020) and spring (October 6, 2020). In each growing season, a total of 50 mangoes were harvested at maturity stage 2, represented by physiologically mature fruit with full shoulders at the stem end (NATIONAL MANGO BOARD, 2010). Mangoes were collected with a homogeneous shape and size and a predominant light green skin colour. After harvest, the fruit were transported to the Postharvest Laboratory at Brazilian Agricultural Research Corporation (Tropical Semi-arid Embrapa), Petrolina, PE, Brazil, and were analyzed for weight, length, ventral diameter, transverse diameter, skin and pulp colour, dry matter, pulp firmness, soluble solids (SS), titratable acidity (TA) and SS/TA ratio.

Weight (g) was determined in a digital balance model AD500 (Marte, Brazil), which has an accuracy range of 0.01 g. Length, ventral diameter and transverse diameter were measured with a digital calliper model CD-6 CS (Mitutoyo Corp., Japan), and expressed in millimetres. Skin and pulp colour were determined with a digital colourimeter model CR-400 (Konica-Minolta Co., Japan), recording the colour attributes L^*, C^* and h^o, where L^* represents the lightness, C^* represents the chroma and h^o represents the hue angle.

Dry matter content was non-destructively measured with a portable near-infrared (NIR) spectrometer Felix model F-750 (Felix Instruments, USA) and the results expressed in percentage. Pulp firmness (N) was measured with a texture analyser TA.XT/Plus (Stable Micro Systems, UK) equipped with a 6-mm-diameter tip. Soluble solids (SS) content was determined in juice samples using a digital refractometer PAL-1 (Atago, Brazil), with results expressed in °Brix. Titratable acidity (TA) was evaluated by titration of 5 mL of juice diluted in 50 mL of distilled water with a solution of 0.1 N NaOH until the pH reached 8.1. The results were expressed in percentage of citric acid. The SS/TA ratio was calculated by dividing the SS content by its respective TA in each sample.

For each quality trait, the average, median, variance, standard deviation, standard error, coefficient of variation, skewness and kurtosis were calculated. The normality of data was analysed by the Kolmogorov–Smirnov test (p<0.05).

In each season, for each quality trait, the sample size (η) was calculated for the half-amplitudes of the confidence interval (estimation errors) equal to 1, 2, ..., 10% of the estimated mean (m), with degrees of confidence ($1 - \alpha$) of 95%, applying the following expression (BUSSAB; MORETTIN, 2017):

$$\eta = [S^2(t_{\alpha/2})]^2/e^2m^2$$

where S is the estimated standard deviation; $t_{\alpha/2}$ is the critical value of Student's t distribution, whose area on the right is equal to $\alpha/2$, with (n-1) degrees of freedom, adopting $\alpha = 5\%$ probability of error; e is the error in the average estimate (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10%) and m is the average.

Statistical analyses were performed using Microsoft Excel® 2016 (Microsoft, USA) and Minitab 19 (Minitab, USA).

Results and discussion

Descriptive statistics represented by average, median, variance, standard deviation, standard error, coefficient of variation, skewness, kurtosis and normality for the physicochemical traits of ‘Palmer’ mangoes harvested in June 2020 (winter) and October 2020 (spring) are presented in Figures 1, 2, 3 and 4.

Data of all traits showed a normal distribution ($p>0.05$), as confirmed by the Kolmogorov-Smirnov test. Normality allowed the comparison between harvests, for each quality trait, by t test, as well as the estimation of sample size based on Student's t-distribution (TOEBE et al., 2011, 2014).

Fruit harvested in spring had higher values for weight, length and ventral and transverse diameters ($p<0.05$), compared with fruit harvested in winter (Figure 1). In winter and spring 2020, the average fruit weight was 427.22 g and 512.00 g, respectively, similar to the values observed by Oldoni et al. (2018) for ‘Palmer’ mangoes grown under the same Semi-arid climate conditions.

Length and ventral and transverse diameters were 3.2%, 5.6% and 6.3% higher in fruit harvested in spring ($p<0.05$), compared with fruit harvested in the winter, respectively. The average values observed for mango diameter were close to those observed in ‘Palmer’ mangoes cultivated under irrigation in Semi-arid (OLIVEIRA et al., 2015) and tropical savanna climate conditions (LIMA et al., 2016).

Mango skin colour parameters are shown in Figure 2. Lightness and hue angle were statistically higher in mangoes harvested in winter, while chroma did not differ between the two harvest seasons ($p>0.05$). In both seasons, hue angle values were close to 120º (Figure 2E and F), indicating a dark green colour (AZZOLINI et al., 2005). Similar results for ‘Palmer’ mangoes were reported at harvest by Sousa et al. (2021). Although skin colour is often associated with other quality traits in fruit (ZIND, 1989; PATHARE et al., 2013), some mango cultivars have a poor relationship between skin colour and the internal quality of the fruit.

All colour parameters in the fruit pulp were statistically different between growing seasons ($p<0.05$), as shown in Figure 3. Fruit harvested in winter had higher lightness and hue angle and lower chroma than those harvested in spring ($p<0.05$). In winter, mango pulp had $L^* = 81.41$, $C^* = 41.77$ and $h^o = 100.62º$ (Figure 3A, C and E), while in spring mango pulp had $L^* = 79.36$, $C^* = 47.97$ and $h^o = 99.28º$ (Figure 3B, D and F). According to Nordey et al. (2019), the pulp colour at harvest is the best indicator of mango maturity and shelf life.

Dry matter (DM) content did not differ between growing seasons ($p>0.05$) (Figure 4A and B). The average DM of 13.56% found in both harvests was lower than that previously reported for the same cultivar and location (SANTOS NETO et al., 2019). DM is the weight of all fruit components except water, including starch, sugar and other cell components stored in the fruit during growth and development on the tree. During fruit ripening, starch is converted into sugars, which makes the DM content at harvest an important quality index that can be used to estimate ready-to-eat mango quality and consumer acceptance (WALSH, 2016).

DM is a physicochemical trait that has been widely studied in mangoes, especially through its non-destructive evaluation using portable near infrared spectrometers (ANDERSON et al., 2017; MARQUES et al., 2016; SANTOS NETO et al., 2019; SUN et al., 2020). Since the DM content at harvest is highly and positively correlated with the sugar content in ready-to-eat mangoes, the higher the DM content at harvest, the higher will be the ready-to-eat mango quality in the market (SANTOS NETO et al., 2018).

The pulp firmness of fruit harvested in spring averaged 105.20 N, similarly to the values found at harvest by Silva et al. (2017) and Sousa et al. (2021). This average is statistically higher ($p<0.05$) than the average observed in fruit harvested in winter (85.91 N) (Figure 4C and D). Pulp firmness is a major fruit quality trait, since it determines mango postharvest shelf life and quality (ALI et al., 2011).

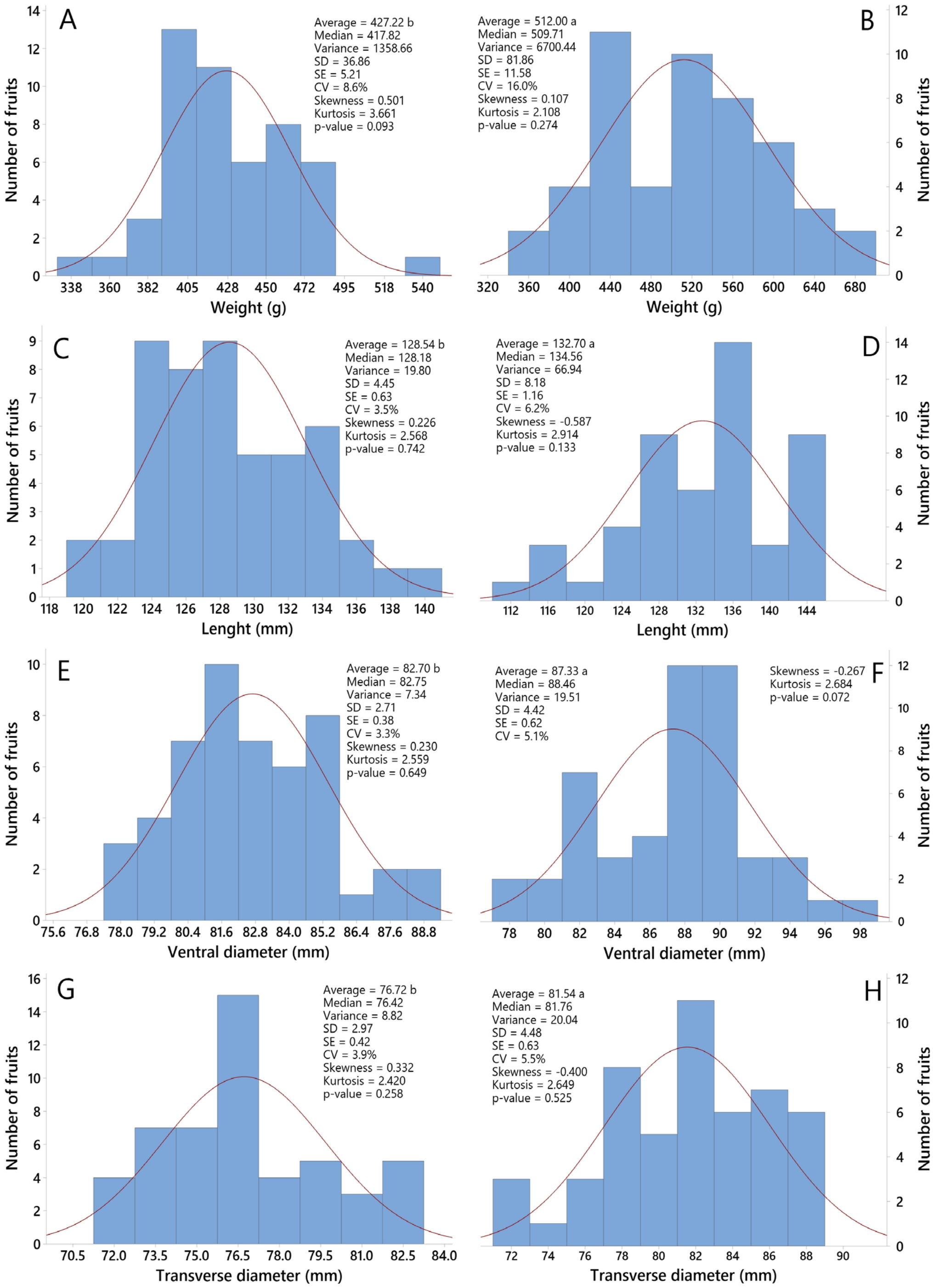

Figure 1. Frequency histogram for weight (A and B), length (C and D), ventral diameter (E and F) and transverse diameter (G and H), measured in 50 'Palmer' mangoes harvested in two growing seasons in Petrolina, PE, Brazil. Figures on the left represent the winter harvest and those on the right the spring harvest. On the histograms, the line represents the normal distribution curve. Values of average, median, variance, standard deviation (SD), standard error (SE), coefficient of variation (CV), skewness, kurtosis and p-value of the Kolmogorov–Smirnov normality test of the traits are shown. In each physicochemical trait, averages followed by the same letter do not differ by the t-test ($p<0.05$).

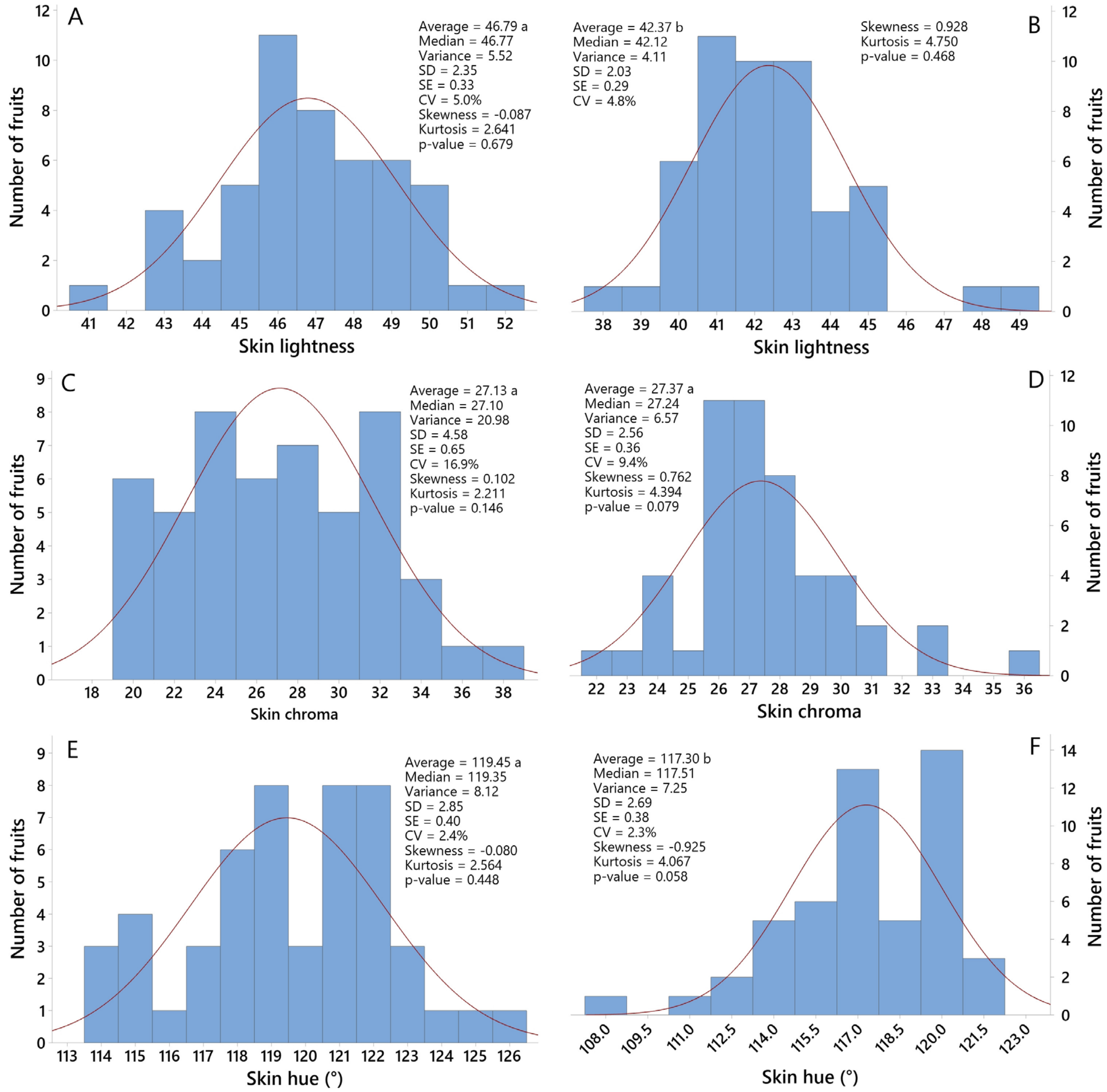

Figure 2. Frequency histogram for lightness (A and B), chroma (C and D) and hue angle (E and F) measured in the skin of 50 ‘Palmer’ mangoes harvested in two growing seasons in Petrolina, PE, Brazil. Figures on the left represent the winter harvest and those on the right the spring harvest. On the histograms, the line represents the normal distribution curve. Values of average, median, variance, standard deviation (SD), standard error (SE), coefficient of variation (CV), skewness, kurtosis and p-value of the Kolmogorov–Smirnov normality test of the traits are shown. In each physicochemical trait, averages followed by the same letter do not differ by the t-test ($p<0.05$).

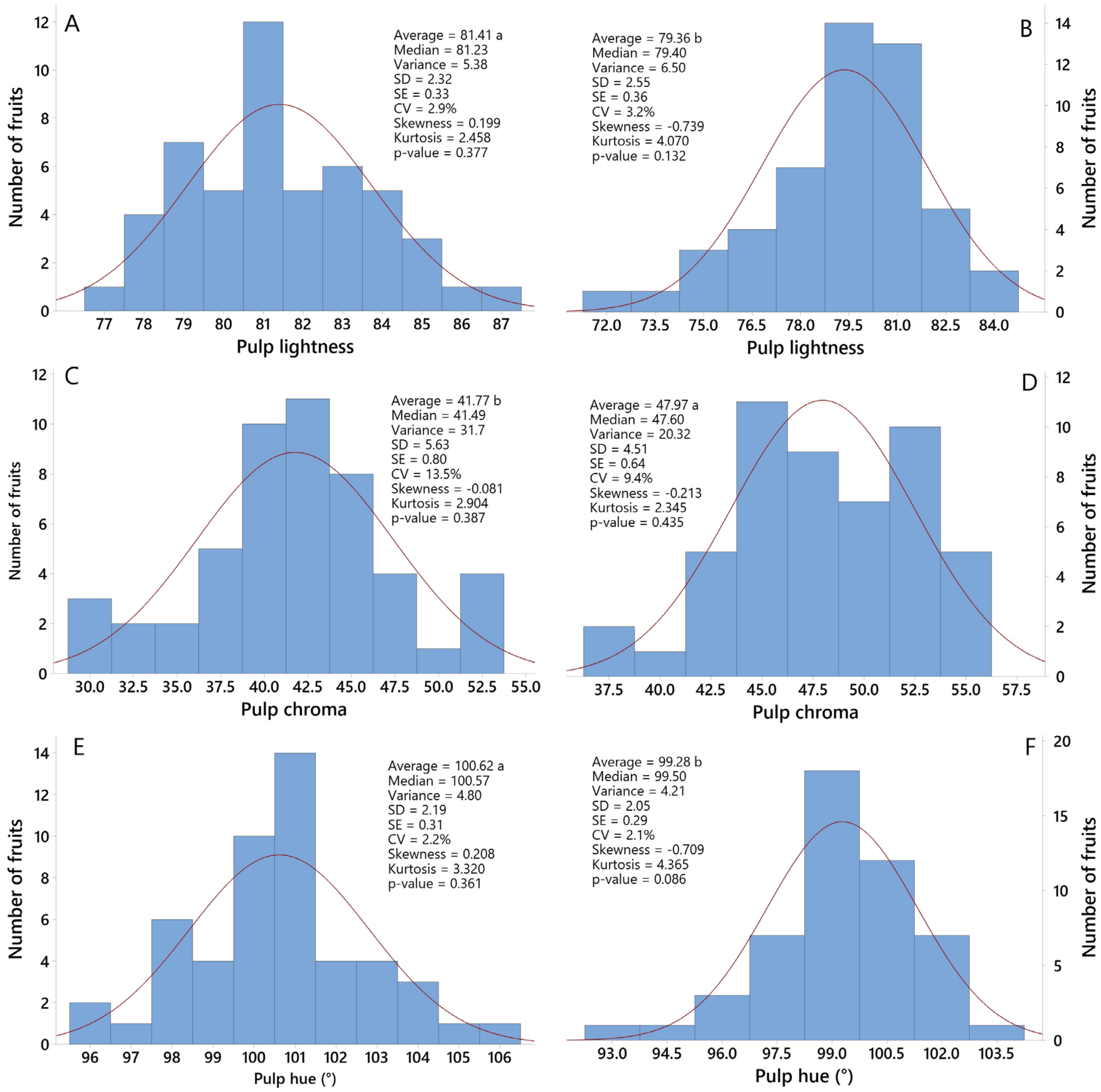

Figure 3. Frequency histogram for lightness (A and B), chroma (C and D) and hue angle (E and F) measured in the pulp of 50 ‘Palmer’ mangoes harvested in two growing seasons in Petrolina, PE, Brazil. Figures on the left represent the winter harvest and those on the right the spring harvest. On the histograms, the line represents the normal distribution curve. Values of average, median, variance, standard deviation (SD), standard error (SE), coefficient of variation (CV), skewness, kurtosis and p-value of the Kolmogorov–Smirnov normality test of the traits are shown. In each physicochemical trait, averages followed by the same letter do not differ by the t-test ($p<0.05$).

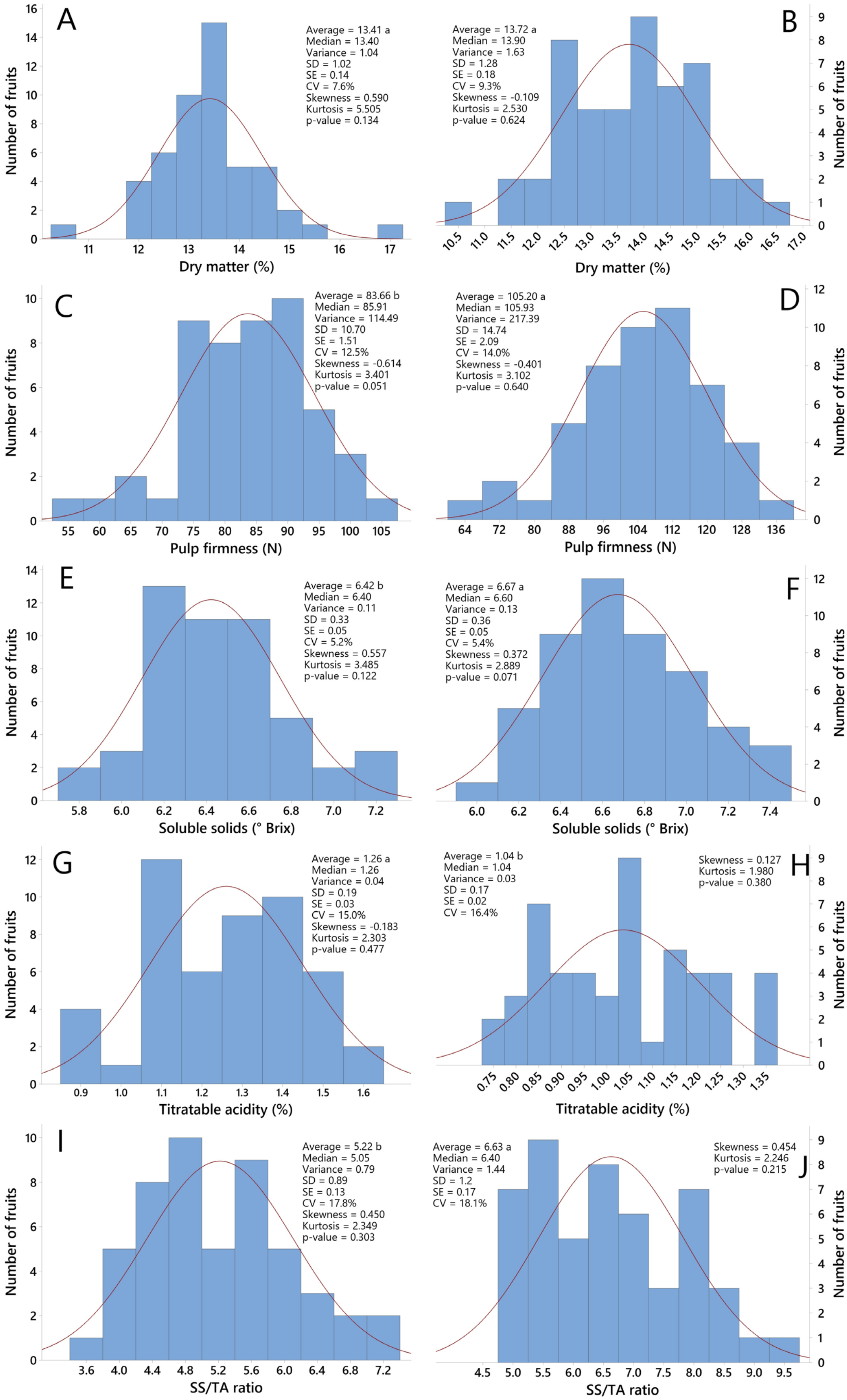

Figure 4. Frequency histogram for dry matter (A and B), pulp firmness (C and D), soluble solids (E and F), titratable acidity (G and H) and SS/TA ratio (I and J), measured in 50 ‘Palmer’ mangoes harvested in two growing seasons in Petrolina-PE, Brazil. Figures on the left represent the winter harvest and those on the right the spring harvest. On the histograms, the line represents the normal distribution curve. Values of average, median, variance, standard deviation (SD), standard error (SE), coefficient of variation (CV), skewness, kurtosis and p-value of the Kolmogorov–Smirnov normality test of the traits are shown. In each physicochemical trait, averages followed by the same letter do not differ by the t-test (p<0.05).

The SS content was statistically different between growing seasons (p<0.05), with average values of 6.42 and 6.67º Brix in fruit harvested in winter and spring, respectively (Figure 4E and F). TA was higher (p<0.05) in winter, averaging 1.26%, and lower in spring, averaging 1.04% (Figure 4G and H). Our results are similar to those reported for the same mango cultivar by Sousa et al. (2021).

The SS/TA ratios were 5.22 and 6.63 in fruit harvested in winter and spring, respectively (Figure 4I and J), with a statistical difference between harvests (p<0.05). The SS/TA ratio is a better indicator of fruit flavour than these parameters individually, since it represents the balance between the content of sugars and organic acids in the fruit (MEDLICOTT; THOMPSON, 1985).

The variability observed among the 50 fruits, evaluated for each physicochemical trait through the coefficient of variance (CV), ranged between 2.2% and 17.8% in winter and between 2.1% and 18.1% in spring harvested mangoes. The highest CV in both harvests was observed for the SS/TA ratio, while the lowest CV was observed for the pulp hue.

Studies have analysed and classified the CV values observed in field experiments for different crop traits (PIMENTEL-GOMES, 2009). According to this classification, three variables analysed in our study (SS/TA ratio, titratable acidity and pulp firmness) have a CV classified as medium (10 < CV < 20%) in both harvests, while the others have a CV classified as low (< 10%) in one or both harvests. There were no variables with a CV classified as high (20 < CV < 30%) or very high (> 30%), according to Pimentel-Gomes (2009). Although valid, this classification is generally based on agricultural and field data and is being used indiscriminately within agricultural experimentation (SCHMILDT et al., 2017b).

For the physical parameters, the CV was higher for weight and lower for ventral diameter, in both harvests (Fig. 1). Among colour attributes, the highest to the lowest CV was found for C^*, L^* and h^o (Fig. 2 and 3). SS content had the lowest CV among chemical attributes, which was 5.2 and 5.4 in winter- and spring-harvested mango, respectively (Fig. 4). The observed low CV values for pulp colour and SS content, together with the importance of these traits as maturity indexes for mango (YAHIA, 2011), suggest that mango maturity can be determined on the basis of these two traits using a lower number of fruit, compared with the other quality traits analysed in our study.

The sample size estimated for each quality trait, in each harvest, is shown in Table 1. Considering an estimation error of 1% and a confidence interval of 95%, the recommended sample size varied between 20 fruits for pulp hue angle and 1174 fruits for the SS/TA ratio, for fruit harvested in winter. In the spring harvest, the recommended sample size ranged from 18 to 1321 fruits, for the same variables, respectively. These sample sizes have excellent accuracy, due to the low estimation error of 1%. However, the evaluation of this high number of fruit is not feasible due to the amount of time and labour required (POLETTO et al., 2018).

Considering a larger estimation error (2%–10%), there is a reduction in sample sizes, but with less precision (CARGNELUTTI FILHO et al., 2015). The relationship between sample size and estimation errors from 1% to 10% is shown in Table 1, which allows the researcher to determine the most convenient sample size by balancing precision with labour and costs required to analyse the samples in the experiment (POLETTO et al., 2018; SILVA et al., 2016). As calculated, with an estimation error of 10% and a confidence interval of 95%, 12 fruits are needed in the winter harvest and 14 in the spring harvest.

The higher the variation, the higher will be the sample size. In both growing seasons, TA and SS/TA were the traits with the highest required sample size. Conversely, very few fruits are required for some physicochemical traits due to low variability, such as length, ventral diameter, transverse diameter, skin hue, and pulp lightness and hue in winter harvest, when only 1 fruit is required. In the spring harvest, the same number of fruits are required to estimate skin and pulp L^* and h^o with an estimation error of 10% and a confidence interval of 95%. These quality traits have also been shown to require small sample sizes to be evaluated in other fruit species, such as yellow passion fruit (COELHO et al., 2011), apple (TOEBE et al., 2014), red mombin (SILVA et al., 2016), pecan (POLETTO et al., 2018) and papaya (SCHMILDT et al., 2019).

Table 1. Sample size (i.e. number of fruits) to estimate the mean of postharvest quality traits of ‘Palmer’ mangoes, with estimation error equal to 1, 2, ..., 10% of the estimated mean, with a 95% confidence level, based on 50 fruits harvested in two seasons in Petrolina-PE, Brazil.

Physicochemical trait	Estimation error (%)									
	1	2	3	4	5	6	7	8	9	10
	Fruits harvested in June (winter)									
Weight	301	76	34	19	13	9	7	5	4	4
Length	49	13	6	4	2	2	1	1	1	1
Ventral diameter	44	11	5	3	2	2	1	1	1	1
Transverse diameter	61	16	7	4	3	2	2	1	1	1
Skin lightness	102	26	12	7	5	3	3	2	2	2
Skin chroma	1152	288	128	72	47	32	24	18	15	12
Skin hue	23	6	3	2	1	1	1	1	1	1
Pulp lightness	33	9	4	3	2	1	1	1	1	1
Pulp chroma	733	184	82	46	30	21	15	12	10	8
Pulp hue	20	5	3	2	1	1	1	1	1	1
Dry matter	236	59	27	15	10	7	5	4	3	3
Pulp firmness	661	166	74	42	27	19	14	11	9	7
Soluble solids	109	28	13	7	5	4	3	2	2	2
Titratable acidity	906	227	101	57	37	26	19	15	12	10
SS/TA ratio	1174	294	131	74	47	33	24	19	15	12
	Fruit harvested in October (spring)									
Weight	1032	258	115	65	42	29	22	17	13	11
Length	154	39	18	10	7	5	4	3	2	2
Ventral diameter	104	26	12	7	5	3	3	2	2	2
Transverse diameter	122	31	14	8	5	4	3	2	2	2
Skin lightness	93	24	11	6	4	3	2	2	2	1
Skin chroma	355	89	40	23	15	10	8	6	5	4
Skin hue	22	6	3	2	1	1	1	1	1	1
Pulp lightness	42	11	5	3	2	2	1	1	1	1
Pulp chroma	357	90	40	23	15	10	8	6	5	4
Pulp hue	18	5	2	2	1	1	1	1	1	1
Dry matter	350	88	39	22	14	10	8	6	5	4
Pulp firmness	793	199	89	50	32	23	17	13	10	8
Soluble solids	117	30	13	8	5	4	3	2	2	2
Titratable acidity	1087	272	121	68	44	31	23	17	14	11
SS/TA ratio	1321	331	147	83	53	37	27	21	17	14

Conclusion

Sample variability differed among physicochemical traits and growing seasons, implying that different sample sizes are required for each trait and growing season. In order to estimate the mean of physicochemical traits of ‘Palmer’ mangoes, 12 fruits are needed in the winter harvest and 14 in the spring, considering an estimation error of 10% and a confidence interval of 95%.

Titratable acidity and the SS/TA ratio required the highest sample size, while the lowest was required to estimate the mean of the colour parameters lightness and hue angle.

Acknowledgments

The authors thank the National Council for Scientific and Technological Development (CNPq), the Coordination for the Improvement of Higher Education Personnel (CAPES) and the Brazilian Agricultural Research Corporation (Embrapa) for financial support, and the company Muranaka Comércio Imp. e Exp. EIRELI (http://www.muranaka.com.br/) for providing the fruit.

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