Characterization of Southeast Asia mangoes (*Mangifera indica* L) according to their physicochemical attributes

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Abstract

Mango (*Mangifera indica*.L.) is an economically important fruit crop grown in the tropics. One of the important traits of mango for successful commercial production is the storage quality of the fruit. This study was conducted to evaluate the postharvest qualities of three mango (*Mangifera indica*) varieties namely 'Chokanan', 'Golden phoenix' and 'Water lily' grown in Southeast Asia regions. The study found that variety and ripening stage had an impact on the postharvest qualities. In general, an increase in weight loss, L* value and soluble solids concentration (SSC) along with a reduction in titratable acidity (TA), firmness and hue value as ripening progressed were observed irrespective of the variety. Analysis of variance and multivariate analysis were used to characterize the ripening process. This study provides useful information for devising strategies in postharvest handling and implementation of breeding programs for mango crop improvement.

Abbreviations: N, Newtons; SSC, soluble solid content; TA, titratable acidity; PCA, principal component analysis

Keywords: Ethylene production; fruit ripening; *Mangifera indica* L; respiration rate; physicochemical characteristics; varieties.

1 Introduction

Mango *(Mangifera indica* L.) is one of the most important tropical fruit crops with significant commercial value. Mango fruit is widely consumed globally due to its juiciness, delicious taste, exotic flavor and nutritional value. In addition, mango fruit is a rich source of health promoting compounds such as carotenoids, ascorbic acids, quercetin and mangiferin (Lauricella *et al.*, 2017). Currently, Asia is the largest mango-producing region, with a production of 34.6 million tons, which accounts for 74.30 % of global mango production. This is followed by America (13.00 %; 4 million tons), Africa (11.00 %; 3 million tons) and a very little portion from Oceania (0.10 %; 0.04 million tons) (FAOSTAT, 2016). There are thousands of mango varieties which are distributed worldwide. Of which, Asia has over 500 fully characterized varieties (Singh *et al.*, 2016). However, only a few of these available mango varieties are traded internationally while most are grown for local consumption (Kuhn *et al.*, 2017). Commercial mango varieties that dominate the global export market include 'Tommy Atkins', 'Haden', 'Ataulfo', 'Kent', 'Keitt' and 'Alphonso' (Bally, 2011; Galán Saúco, 2015; Nassur *et al.*, 2015). Mango varieties in Malaysia include 'Chokanan', 'Harumanis', 'Sala', 'Masmuda' and 'Maha 65' amongst others (MOA, 2016). However, these varieties have not attained equal international popularity as compared to Indian or Floridian varieties due to lack of research attention (Abu Bakar and Fry, 2013).

Fruit ripening involves a spectrum of significant physiological, biochemical and molecular changes that give rise to an edible fruit of desired quality (Barry and Giovannoni, 2007). An increased rate of respiration and ethylene production during ripening has been documented extensively in climacteric fruit such as papaya (Ong *et al.*, 2013) as well as in mango ripening process (Khaliq *et al.*, 2015; Palafox-Carlos *et al.*, 2015; Zerbini *et al.*, 2015). The period of fruit ripening is also characterized with an increase in sugar content and color changes (Palafox-Carlos *et al*., 2015; Ibarra-Garza *et al*., 2015). Mango peel color changes facilitate the identification of the appropriate maturity stage for harvesting and consumption albeit not all varieties change from green to yellow/orange upon ripening (Yahia, 2011). Mango ripens within 4-9 days (variety dependent) (Carrillo-Lopez *et al*., 2000; Srivastava *et al*., 2016) although there has been reports on 'Alphonso' and 'Banganapalli' mangoes with a ripening duration of 12-18 days from harvest (Deshpande *et al*., 2017; Nambi *et al*., 2015). At cold storage (13 °C), mango can be stored for up to 2-3 weeks (Carrillo-Lopez *et al*., 2000).

As postharvest qualities may differ according to varieties, it is necessary to carry out specific studies on each local mango variety in order to uncover their potential to become a commercial marketable fruit. Such information will provide an insight into the development of postharvest strategies towards mango fruit quality improvement and open new marketing opportunities to the farmers and to the local industry. To date, only a few published results on the physicochemical and physiological profile of locally produced mangoes in the literature are available (Bejo and Kamaruddin, 2014; Mansor *et al*., 2011; Khaliq *et al*., 2015; Zakaria *et al*., 2012). Therefore, the objectives of this study were to evaluate the effect of ripening on the physicochemical characteristics and physiological behavior of 'Chokanan', 'Golden phoenix' and 'Water lily' mango varieties, which are grown in the Southeast Asia regions.

2 Materials and Methods

2.1 Mango samples

Mature green mangoes (*Mangifera indica* vars. 'Chokanan', 'Golden phoenix' and 'Water lily') of maturity index 2 (FAMA, 2017) were purchased from a mango farmer in Malacca, Malaysia.

Mango fruit were selected for uniformity in size, shape and absence of external injury. After sorting, fruit were washed, dried and allowed to ripen at ambient temperature (25 ± 1 °C, 80 ± 5 % relative humidity). Assessment of postharvest quality parameters were observed on arrival (0th day) and at 2 day intervals of the ripening period. At each evaluation time, four replicates consisting of three individual fruit per replicate were randomly sampled for each mango variety. The analyses were conducted at the Postharvest Laboratory, School of Biosciences, University of Nottingham Malaysia Campus.

2.2 Determination of physicochemical parameters

Evaluation of physicochemical parameters was carried out as reported by Ali *et al.,* (2016). Weight loss determination was obtained by weighing mango on the 0th day of storage and at 2 day intervals over the storage period. The percentage weight loss was calculated relative to the initial weight.

Peel color was assessed on the basis of the Hunter Lab System using a MiniScan XE Plus colorimeter and presented in the values of L* a* b* and h°. The L* coordinate indicates brightness of color with values ranging from 0 = black to 100 = white. Coordinates, a* and b*, indicate color directions: +a* is the red direction, –a* is the green direction, +b* is the yellow direction, and –b* is the blue direction. From these values, hue angle (h°) was calculated as h° = tangent^{-1} b*/a*) where 0° = red purple, 90° = yellow, 180° = blue-green and 270° = blue. Fruit firmness was assessed using an Instron Universal Testing Machine (Instron 2519-104, Norwood, MA). Measurements were taken from three points of the equatorial region for each sampled fruit. An average of three readings was obtained and expressed in Newtons (N). The same fruit pulp samples (10 g) used in the firmness evaluation were homogenized using a kitchen blender (Philip, Malaysia) with 40 ml of distilled water, and filtered through a double layer of muslin cloth to extract juice for further analyses. Soluble solid content (SSC) was determined with a droplet of the filtrate using a Palette Digital Refractometer (Model: PR-32α, Atago Co Ltd., Japan) and expressed as a percentage (%). Titratable acidity (TA) was determined by titration of 5ml of filtrate with 0.1 N NaOH to an endpoint of pH 8.1 by two drops of 0.1 % phenolphthalein indicator. The results are expressed as a percentage of citric acid equivalents.

2.3 Respiration and ethylene production

The respiration and ethylene production of mango fruit were carried out as described by Ong *et al*., (2013). Fruit were placed in a plastic container tightly sealed with a lid. After 1 hour of incubation, 1 ml of gas sample was withdrawn from the headspace and analyzed in the gas chromatograph (GC) (Clarus-500 Perkin-Elmer, USA) equipped with a column (Agilent J&W, DB-5MS column: 30 m in length, 0.25 mm in diameter and 0.25µm in film thickness) with two detectors connected in series; a thermal conductivity detector (TCD) and flame ionization detector (FID) for the quantification of carbon dioxide (CO_2) and ethylene respectively. Helium was used as the carrier gas for thermal conductivity (TCD) and temperatures were 60 °C, 150 °C and 200 °C for the oven, injector and detector respectively. The injector, oven and detector temperatures were 200 °C, 120 °C and 250 °C respectively with nitrogen as the carrier gas for the flame ionization detector (FID). Concentration of the standards used was 1.0 % CO_2 and 1 ppm ethylene (C_2H_4). Respiration and ethylene production rate are expressed as nmol kg^{-1} s^{-1} according to Banks *et al*., (1995).

2.4 Statistical analysis

The experiments were conducted according to a completely randomized design (CRD) in four replications. For each replicate, three fruit were randomly selected for analysis at each evaluation time. Data were subjected to analysis of variance (ANOVA) using the GENSTAT (18th edition) software. Means were separated using Duncan's Multiple Range Test (DMRT; $p < 0.05$). Multivariate analysis was carried out using the XLSTAT (Addinsoft, New York, USA). PCA was performed to predict the total variability between days of ripening and mango varieties. The Pearson's correlation coefficient was employed to explore the relationship between the postharvest parameters.

3 Results

3.1 Changes in physical quality parameters

Based on the external appearance and postharvest changes score, 'Golden phoenix', 'Water lily' and 'Chokanan' mango varieties were found to achieve ripeness at 7, 7 and 9 days respectively.

3.1.1 Weight loss

A progressive weight loss was observed during ripening for all the varieties under study (Fig. 1). It increased significantly ($p < 0.05$) over the ambient storage period. 'Chokanan' variety exhibited a 2.3 % weight loss after two days of storage (Fig 1a). The highest rate of weight loss (6.98 %) was noticed on the 8th day of ripening for 'Chokanan' (a mean loss of 0.76 % per day). As can be seen in Fig. 1b, weight loss in 'Golden phoenix' variety significantly increased ($p < 0.05$) from the 2nd (2.76 %) to 4th day (5.78 %). The percentage weight loss observed on the 4th day was not significantly different ($p < 0.05$) from that obtained on the 6th day of ripening. At the end of storage, 'Golden phoenix' had lost 7.76 % of initial weight with an average of 1.20 % per day. 'Water lily' lost 2.48 % of its initial weight after two days of storage and this was maintained with significant differences ($p < 0.05$) until the 6th day (Fig. 1c). At the end of storage, it attained an 8.44 % weight loss which averaged 1.40 % per day.

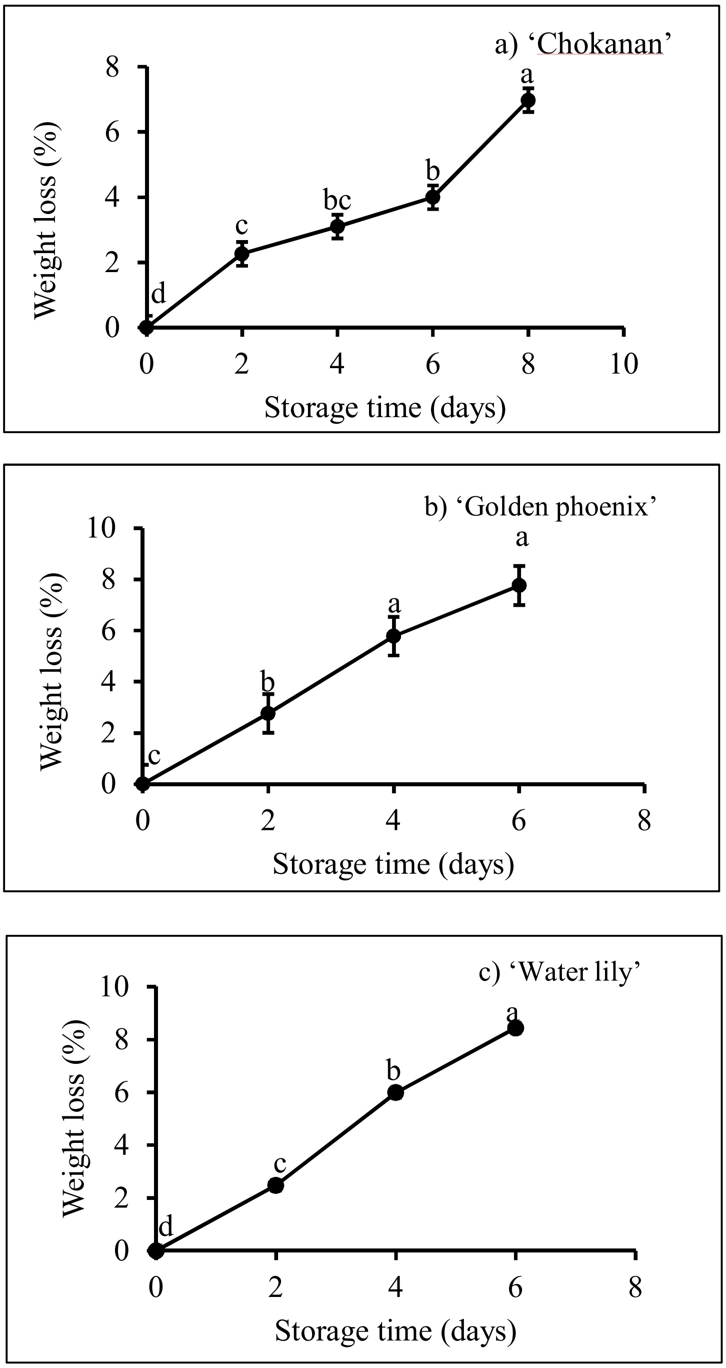

Figure 1: Weight loss of a) ‘Chokanan’, b) ‘Golden phoenix’ and c) ‘Water lily’ mango varieties during storage. Note: Vertical bars indicate standard error of mean of four replicates per variety. Different letters indicate significant difference between storage times at $p < 0.05$ for each mango variety

3.1.2 Peel color

The external appearance of each variety at the beginning and end of storage is presented in Fig. 2. Color parameters as influenced by the ripening period are provided in Table 1. As ripening progressed, the peel color changed from green to slightly or full yellow color depending on variety. The visual skin color of 'Chokanan' changed noticeably to yellow during fruit ripening (Fig. 2). The L* value (lightness) of 'Chokanan' was 53.63 on the 0th day of storage and gradually increased as the fruit ripening advanced (Table 1). When 'Chokanan' was fully ripened after eight days, there was a significant ($p < 0.05$) increase in lightness to 63.78. 'Chokanan' peel color exhibited a decline in hue angle, which started at 118.20 and was maintained with significant differences from the 2nd to 8th day of storage (Table 1). An increasing trend was also observed on the peel a* and b* values during ripening. 'Golden phoenix' showed no conspicuous changes of peel color from green to yellow upon ripening (Fig. 2). Lightness (L*) value of the 'Golden phoenix' peel increased, beginning on the 2nd day and presented no significant changes until the end of storage. Similarly, there was a gradual increase in peel a* value beginning on the 2nd day, and higher b* values on day four (Table1). Meanwhile, hue angle dropped progressively from 119.03 to 108.61 during the ripening period. In 'Water lily' variety, hue angle decreased from 120.4 to 103.3 with significant differences ($p < 0.05$) between the storage times (Table 1). A progressive increase in peel a* value beginning on day two, and higher L* value on day four (Fig. 2) were observed. Similarly, an increasing trend was observed for b* values with significant differences ($p < 0.05$) between storage time. Overall, the peel colors of the three mango varieties under study became lighter (higher L* values), less green (increased a* values) and tended to be more yellow (increased b* values) as ripening time progressed.

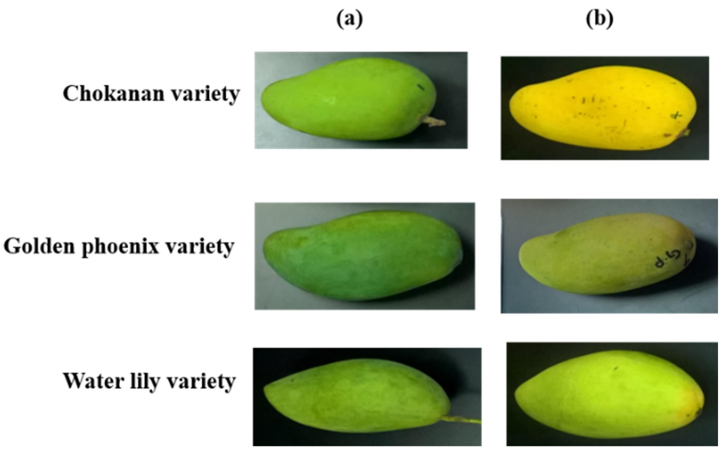

Figure 2. External peel color appearance of mango varieties.
(a) Fruit samples on arrival (day 0) and (b) samples at the end of storage (8th day for 'Chokanan' and 6th day for 'Golden phoenix' and 'Water lily' respectively).

Table 1: Changes in peel color in mango (*Mangifera indica* L.) varieties ('Chokanan', 'Golden phoenix' and 'Water lily') during storage.

Variety/ storage time	Hue	L* value	a* value	b* value
'Chokanan'				
0	118.20a	53.63d	-16.33d	30.75d
2	116.61a	58.46c	-15.72d	34.53c
4	107.38b	60.22bc	-12.76c	41.38b
6	101.45c	62.53ab	-8.96b	43.51b
8	89.63d	63.78a	-1.31a	53.27a
'Golden phoenix'				
0	119.03a	49.38b	-15.71c	28.70b
2	116.10b	54.80a	-14.74bc	30.40b
4	110.49c	54.83a	-13.68ab	36.94a
6	108.61c	57.59a	-12.64a	37.96a
'Water lily'				
0	120.40a	49.00b	-17.53c	29.90d
2	117.00b	52.65b	-17.13bc	33.89c
4	110.50c	57.85a	-15.38b	41.10b
6	103.30d	57.92a	-11.31a	48.20a

Note: L*, a* and b* indicate lightness, indexes of red/green and yellow/blue color of fruit respectively. Hue describes the visual color of the fruit. Values are means of four replicates. Different letters mean significant difference between storage times at $p < 0.05$ for each mango variety.

3.1.3 Pulp firmness

Over the period of storage time, a loss of pulp firmness was observed in all mango varieties under study. Firmness of 'Chokanan' decreased significantly ($p < 0.05$) during storage from 138.18N to 12.67N after eight days (Fig. 3a). There were no significant firmness changes during the first two days. A rapid loss of firmness (82.86 %) took place in 'Chokanan' between 2nd and 6th day of storage, with slow changes thereafter. In 'Golden phoenix', decline in firmness which started at 109.22N was maintained with significant differences ($p < 0.05$) between sampling points (Fig.3b). A significant decrease in firmness had begun on the second day by up to 36 % for 'Golden phoenix'. Firmness values at the end of storage (9.53 N) resulted in total loss of 91.27 % of the firmness recorded compared to the beginning of the study. For 'Water lily' variety, the firmness value decreased significantly during storage from 104.47 to 7.50 N after six days (Fig. 3c). A sharp decline was observed until the 4th day of ripening (16.61 N, 84 % loss), whereas from the 4th to the 6th day of ripening, the loss in fruit firmness remained negligible. At the end of the ripening period, 'Water lily' had lost 92.82 % of its initial fruit firmness.

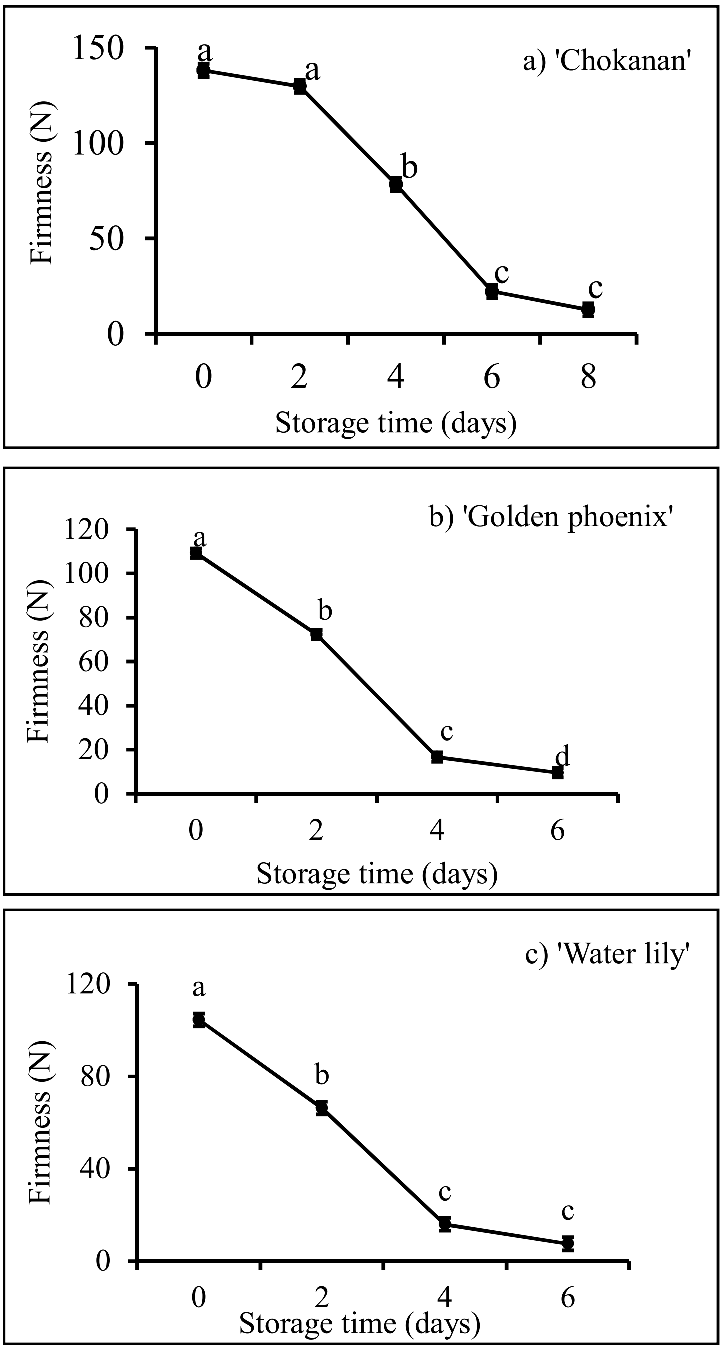

Figure 3. Firmness of a) 'Chokanan' b) 'Golden phoenix' and c) 'Water lily' mango varieties during storage. Note: Vertical bars indicate standard error of mean of four replicates per variety. Different letters indicate significant difference between storage times at $p < 0.05$ for each mango variety

3.1.4 Titratable acidity (TA) and soluble solids content (SSC)

In general, SSC value increased while TA declined during storage regardless of the variety. Changes in SSC and TA observed are shown in Fig. 4. The initial SSC content for ‘Chokanan’ was 6.83 % and it peaked ($p < 0.05$) at 16.80 % on the 8th day of storage (Fig. 4a) when the fruit was ripe (as depicted by the peel coloration; Fig. 2). SSC did not present much variation between storage days. TA decreased from 1.05 % on day zero to 0.26 % on the 8th day of ripening. SSC value in ‘Golden phoenix’, which started at 7.18 % was maintained with significant differences between the days of ripening (Fig. 4b). However, on the 6th day of storage the highest SSC value (20.30 %) was observed. A decrease in TA was recorded for ‘Golden phoenix’ from 0.69 % to 0.19 %, which was not statistically different ($p > 0.05$) between the 2nd and 4th day of storage. In ‘Water lily’, a significant increase in SSC value beginning on day four was recorded. The value was maintained until the end of the storage (Fig. 4c). However, changes in SSC were negligible between day four and six. While SSC increased, TA decreased from 0.34 % to 0.12 % after six days of ripening.

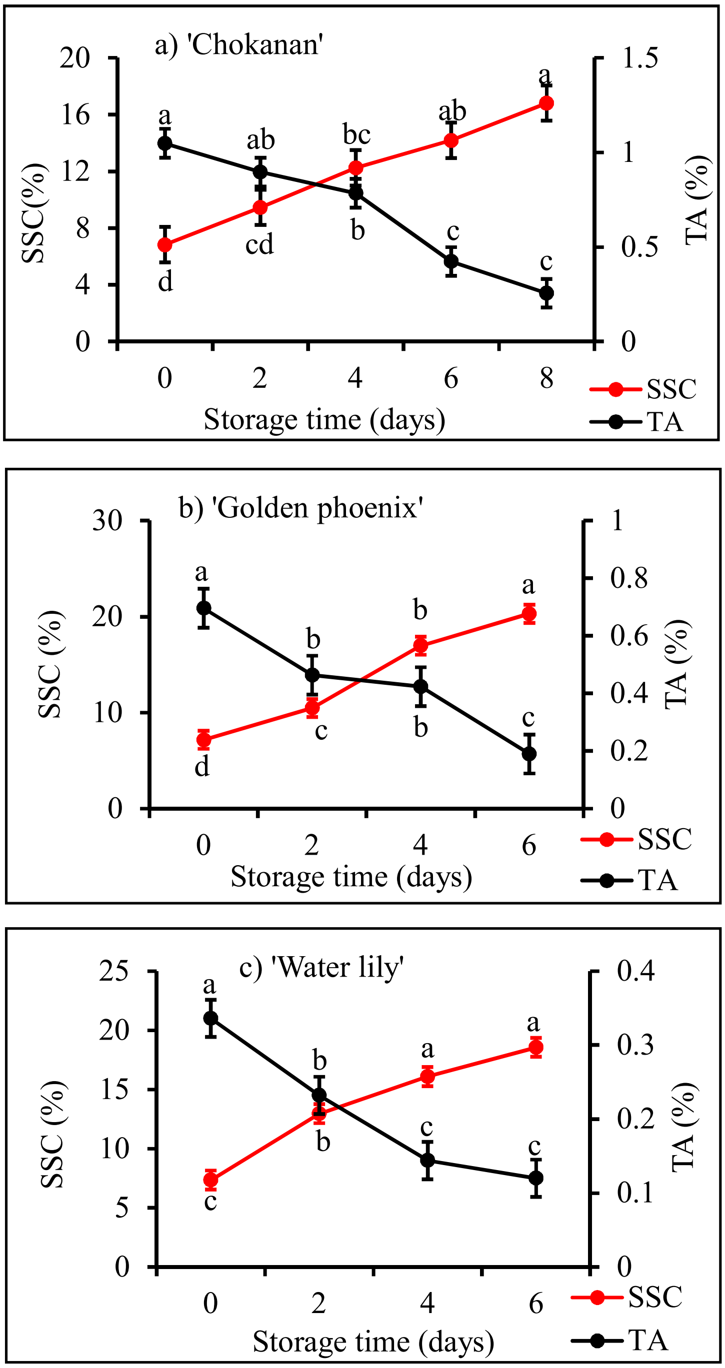

Figure 4. Titratable acidity and soluble solid concentration of (a) 'Chokanan' (b) 'Golden phoenix' and (c) 'Water lily') mango varieties during storage. Note: Vertical bars indicate standard error of mean of four replicates per variety. Different letters indicate significant difference between storage times at $p < 0.05$ for each mango variety. SSC, soluble solid concentration; TA, titratable acidity

3.1.5 Respiration and ethylene production

A typical climacteric pattern of respiration and ethylene production was observed in all mango varieties during ripening (Fig. 5). In 'Chokanan', a respiratory climacteric was apparent on the 4th day of storage and peaked at 579.40 nmol kg^{-1} s^{-1} on the 6th day (Fig. 5a) when fruit exhibited a more yellow peel color. Ethylene production also peaked on the 6th day with a maximum value of 0.010 nmol kg^{-1} s^{-1} and decreased afterwards (Fig. 5a). Respiration rate of 'Golden phoenix' was 279.10 nmol kg^{-1} s^{-1} on day zero reaching a climacteric maximum of 939.3 nmol kg^{-1} s^{-1} on the 4th day. This was followed by a decrease to 797.70 nmol kg^{-1} s^{-1} on the sixth day (Fig. 5b). Maximum production of ethylene was observed in fruit from the 4th day (0.011 nmol kg^{-1} s^{-1}) (Fig. 5b). In 'Water lily' a respiratory climacteric was apparent after two days in storage and peaked at 1161.40 nmol kg^{-1} s^{-1} on the 4th day (Fig. 5c). Ethylene production also peaked on the 4th day of storage with a maximum value of 0.013 nmol kg^{-1} s^{-1} (Fig. 5c). At that moment the production peaks, it declined until the end of the storage.

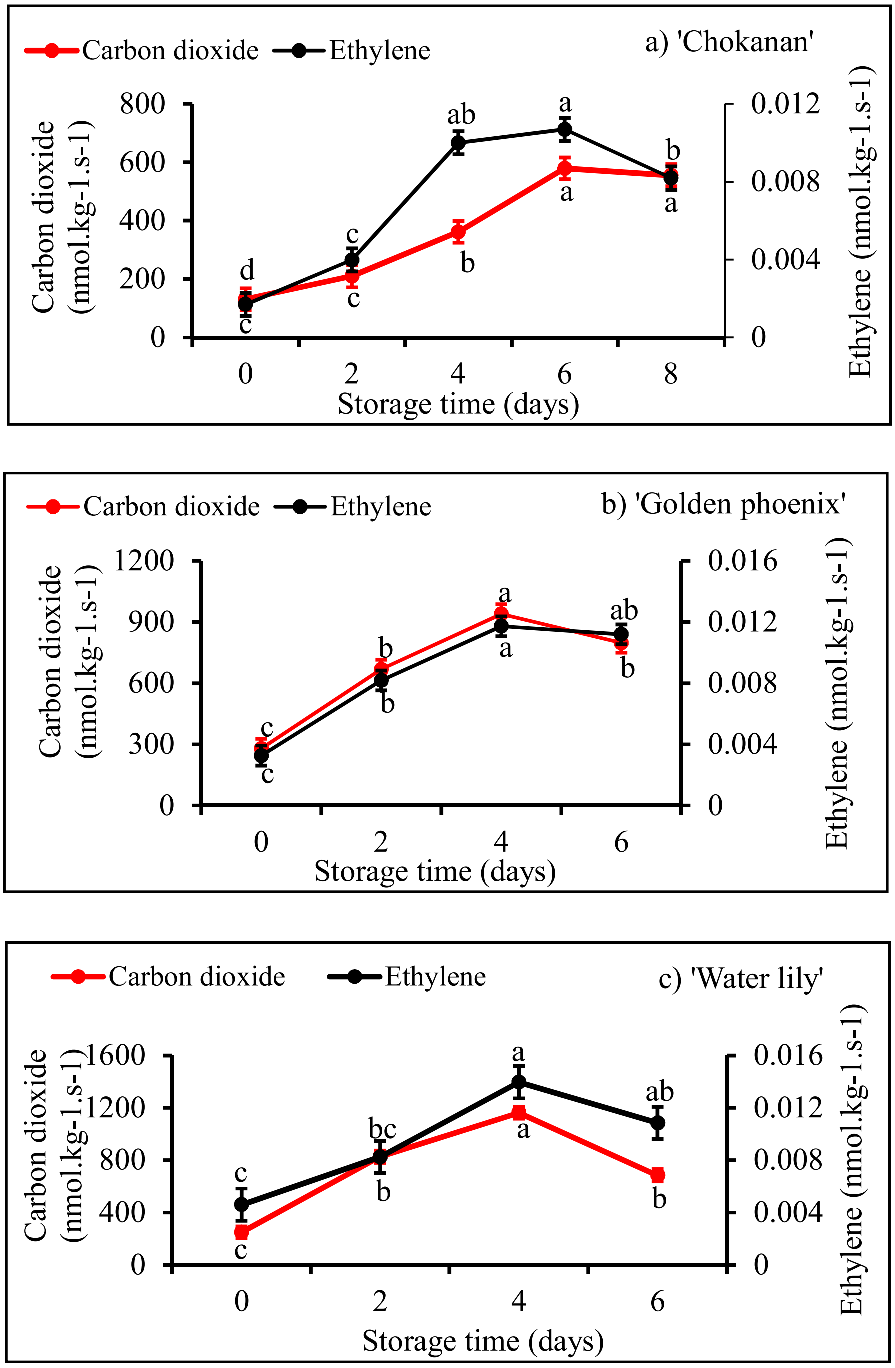

Figure 5: Respiratory pattern and ethylene production of (a) ‘Chokanan’ (b) ‘Golden phoenix’ and (c) ‘Water lily’) mango varieties during storage. Note: Vertical bars indicate standard error of mean of four replicates per variety. Different letters indicate significant difference between storage times at $P < 0.05$ for each mango variety

3.2 Multivariate analysis of postharvest quality parameters

Pearson's correlation coefficient (r) was employed to explore the relationship between the postharvest quality parameters during fruit ripening. Results are presented in Table 2. Respiration showed a significant ($p < 0.05$) positive correlation between ethylene ($r = 0.84$) and SSC ($r = 0.67$). Ethylene also showed a significant positive correlation with SSC ($r = 0.67$, $p = 0.012$) and a negative correlation with firmness ($r= -0.81$, $p < 0.01$) and TA (-0.60, $p = 0.029$) respectively. Firmness was positively correlated with hue ($r = 0.59$, $p = 0.035$) and TA ($r = 0.86$, $p < 0.01$) while a negative correlation was shown for b* value ($r = -0.76$, $p < 0.01$) and SSC ($r = -0.86$, $p <0.01$).

Furthermore, to obtain a broader view on the postharvest quality changes that occurred during fruit ripening, the whole data set was subjected to principal component analysis (PCA) using the correlation matrix. The first principal component (F1) explained up to 62.18% of total variance and PC2 explained 21.59 %, totaling 83.77 %. The rest of the components varied to a less extent with 16.23 % of total variance. The samples of all varieties were well separated on the PCA biplot (Fig. 6). Samples were separated along the first principal component (F1) based on firmness, SSC, TA, b* value, ethylene and respiration rate. The second PC classified the samples related to their external coloration (hue, L* and a* values). The positive contribution on F1 dimension is due to high TA and firmness, whereas the negative contribution is due mainly to high SSC, respiration and ethylene rate. Separation of samples according to their ripening state was achieved on F1 dimension, with unripe fruit located at the right hand side and ripe fruit on the left hand side. In other words, unripe fruit have a higher firmness and TA while ripe fruit have higher SSC. The contribution of b* value tells us that there is a great variability between unripe and ripe fruit of the studied mango varieties based on their yellowness although this is more conspicuous in 'Chokanan' variety (Fig. 2). On the other hand, F2 dimension showed separation related to the variety effect, with 'Chokanan' samples at the top (increased L* and a*) and the other varieties on the lower region (high hue values). However, no clear demarcation was achieved for 'Waterlily' and' Golden phoenix' varieties. This could be due to a lesser variability of the color coordinates (hue, L* and a*) on the F2 dimension between these varieties. The green coloration retained by these varieties ('Waterlily' and 'Golden phoenix') upon ripening supports this possibility (Fig. 2). More positive scores along F2 dimension for 'Chokanan' on the 8th day of storage could be as a result of further accumulation of pigmentation yielding more yellow coloration as ripening progresses.

Table 2: Correlation matrix among postharvest quality variables

Variables	Respiration	Ethylene	Firmness	Hue	a*	L*	b*	TA	SSC
Respiration	1	0.84*	-0.81*	-0.26	0.17	0.19	0.52	-0.60*	0.67*
Ethylene		1	-0.79*	-0.47	0.30	0.38	0.74*	-0.59*	0.67*
Firmness			1	0.59*	-0.49	-0.37	-0.76*	0.86*	-0.86*
Hue				1	-0.96*	-0.90*	-0.51	0.34	-0.69*
a*					1	0.83*	0.31	-0.26	0.58*
L*						1	0.39	-0.10	0.57*
b*							1	-0.62*	0.71*
TA								1	-0.64*
SSC									1

* indicates significance of correlation at the level of 0.05. SSC, soluble solid concentration; TA, titratable acidity.

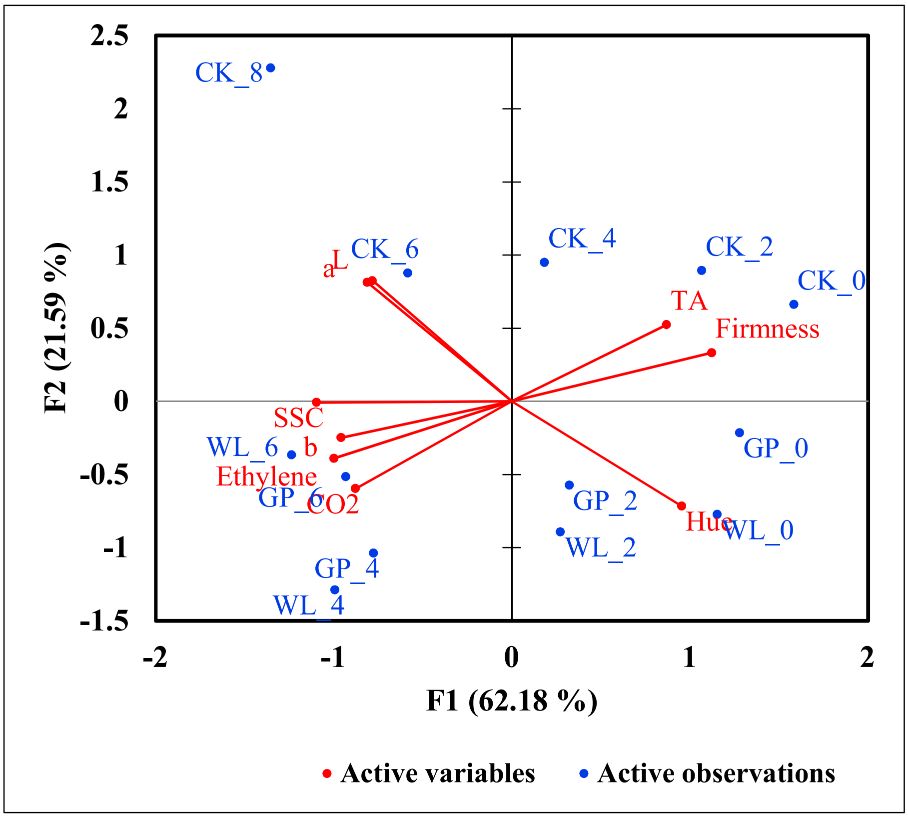

Figure 6. PCA biplot of the postharvest quality attributes in the three mango varieties 'Chokanan' (CK), 'Golden phoenix' (GP) and Waterlily (WL) on 0th day (0), 2nd day (2), 4th day (4), 6th day (6) and 8th (8). (L, L* value; a, a* value; b, b* value; CO_2, carbon dioxide; SSC, soluble solid content; TA, titratable acidity).

4 Discussion

4.1 Changes in postharvest qualities

4.1.1 Weight loss

Weight loss is an aspect that determines the storage life and quality of fruit. Harvested fruit continue to respire and lose water to the environment. In mango, water loss through the stomata and lenticels seems to be the possible reason for physiological weight loss during storage (Brecht and Yahia, 2009). The results from this study are in line with the findings obtained from 'Dashehari' mango (Gupta and Jain, 2012) and other climacteric fruit such as papaya (Ong *et al*., 2013) at ambient storage. However, the variability among species, varieties, ripening stage and storage conditions could be possible factors explaining the differences (Kader, 2002).

4.1.2 Peel color changes

A change in peel color is mainly caused by the degradation of chlorophyll and accumulation of pigments such as carotenoid, xanthophyll and lycopene (Ornelas-Paz *et al*., 2008). The peel color showed a reduction in hue values and increase in L* value, characterizing the loss of the green color during fruit ripening. However, our results show that peel color is not a stand-alone indicator but rather more useful when combined with other quality parameters throughout ripening period. The results from this study show similar trends to those observed in other mango varieties (Ibarra-Garza *et al*., 2015; Palafox-Carlos *et al*., 2015).

4.1.3 Loss of fruit firmness

'Chokanan' variety has been reported to be a firm variety in comparison with other varieties under study (Jarimopas and Kitthawee, 2007; Vásquez-Caicedo *et al*., 2002). This is in agreement with our observations for 'Chokanan' variety having a longer storage period.

Decreased fruit firmness has been reported in other mango varieties (Jha *et al*., 2013; Ibarra-Garza *et al*., 2015; Palafox-Carlos *et al*., 2015). Flesh firmness is of great concern in mango as it plays an integral role in shelf life, pathogen resistance, transportation and storage of the fresh produce. Loss of flesh firmness has been reported to be associated with the cell wall modification and starch hydrolysis (Muda *et al*., 1995). The best organoleptic quality of mango fruit is when they are soft with a pulp firmness between 4.5 N and 26. 7 N (Nassur *et al*., 2015).

4.1.4 Titratable acidity and soluble solids concentration

TA and SSC play an important role in both fresh and processing markets of table fruit. The patterns of TA and SSC observed in this study have been similarly reported for other mango varieties such as 'Ataulfo' (Palafox-Carlos *et al*., 2015), 'Haden' (Nassur *et al*., 2015) and 'Keitt' (Padda *et al*., 2011). However, the different acidity values obtained in the respective studies reflects variations exist among various mango varieties (Yahia, 2011). Decline in acidity is attributed to their utilization as substrates for respiration and conversion to sugars as ripening progresses (Espitia *et al*., 2012). SSC values for 'Chokanan' variety were similar to those reported by Bejo and Kamarudin, (2011) from the same variety and geographical region. Overall, studies on other mango varieties (Nassur *et al*., 2015; Ibarra-Garza *et al*., 2015; Padda *et al*., 2011; Palafox-Carlos *et al*., 2015) corroborate with the findings generated in this studies. The SSC of all the ripe mango varieties in this study fitted well with the 10-20 % SSC requirement for ripe mangoes (Mitcham, 2012; Yahia, 2011).

4.1.5 Respiration and ethylene production

Climacteric fruits such as mango are characterized by an increase in respiration rate and ethylene production. Based on the results, it can be inferred that the climacteric rise in mango fruit occurred when it was considerably ripe. Similar patterns have been reported for other mango varieties such as 'Ataulfo' (Palafox-Carlos *et al*., 2015) and 'Cogshall' (Nordey *et al*., 2016). In contrast, 'Amrapali' and 'Dasheri' mangoes did not follow a climacteric pattern (Reddy and Srivastava, 1999). Similar ethylene production rates recorded in this study were reported for other mango varieties such as 'Carabao' (Cua and Lizada, 1990), 'Kesington pride' (Lalel *et al*., 2003) and 'Ataulfo' (Palafox-Carlos *et al*., 2015). As observed by these authors, the outburst of ethylene may precede, coincide or lag behind the respiratory peak during mango ripening. The comparison of the respiration profiles and the ethylene production for the three mango varieties revealed that the two physiological processes occurred in a similar way.

Furthermore, the mangoes investigated in this study were comparable to the globally traded mango varieties (Appendix Table 1). The tropical mango varieties under study did not differ greatly from the commercial mangoes reported so far in terms of their postharvest quality parameters including pulp firmness, soluble solids and titratable acidity. On the other hand, the peel color of 'Golden phoenix' and 'Water lily' varieties tended to be higher, characterizing by their green fruit coloration (Fig. 2) upon ripening compared to the other varieties. Since peel color is one of the most important visual attributes in mango that drives marketability and consumption (Jha *et al*., 2013; Nassur *et al*., 2015), this quality of not attaining a full yellow coloration may influence the consumer acceptance of 'Golden phoenix' and 'Water lily' mangoes in the international market (Jha *et al*., 2013; Nassur *et al*., 2015). Regarding firmness and SSC, the Southeastern mangoes fitted well at 4.5 – 26 N pulp firmness (Nassur *et al*., 2015) and 10 - 20 % SSC (Mitcham, 2012; Yahia, 2011) requirement for ripe mangoes. Even though 'Golden phoenix' and 'Water lily' mangoes show green coloration upon ripening, utilization of these varieties in the pulping industry for mango purée and juices may be a good option because of the soluble solid concentration and acidity level (Nambi *et al*., 2015; Vásquez-Caicedo *et al*., 2002). Taken together, the results of this study offer new insights to uncover the potential of the investigated mango varieties to become commercially marketable fruits.

4.2 Multivariate studies

Pearson's correlation coefficient was employed to explore the relationship between the postharvest quality parameters during fruit ripening. The positive relationship between SSC and b* value can be explained by the observation that as ethylene, respiration and SSC increases during ripening, the fruit becomes less acidic and firm. The negative correlation between hue and the other color coordinates (b* and L* values) is expected because as a mango fruit ripens, these values increases with pigment accumulation leading to a reduced hue value (fruit becoming brighter and more yellow). Correlation of some postharvest parameters observed in this study are in line with studies in mango (Nambi *et al*., 2015) and tomato (Aoun *et al*., 2013). Hue was not significantly correlated with respiration and ethylene, which agree with the observation by Ketsa *et al*., (1999) who found that 'Tongdum' mangoes, which remained green upon ripening had high ethylene production compared with 'Nam Dok Mai' mangoes, which turn completely yellow. Similar discrimination based on fruit ripening stages as observed in this study has been reported in other mango varieties (Nambi *et al*., 2015; Padda *et al*., 2011) and banana (Valérie Passo Tsamo *et al*., 2014). As the fruit ripened, there was a shift from right to left along F1 (Fig. 6) with increase in SSC, yellowness (b* value), ethylene and respiration rate. In this study, decrease in acidity and firmness in unripe fruit, was also characterized by a shift from right to left, reflecting the ripening process in the mango varieties. The two principal components played an important role in explaining the total variation of the external appearance in this study since color coordinates (hue, L*, b*and a* values) were distributed over the PCA biplot. The lack of separation between 'Golden phoenix' and 'Water lily' mangoes on the F2 dimension could be due to a lesser variability of the changes in color coordinates (hue, L* and a* values) between 'Golden phoenix' and 'Water lily' varieties as ripening progressed over the storage time. There is a huge variability of postharvest attributes among mango varieties. For this reason, a common classification of postharvest qualities is not suitable for all mango varieties (Nambi *et al*., 2016). Multivariate comparisons clearly indicated the correlation between the physicochemical parameters and their relationship in different mango fruit varieties during the ripening period. The present postharvest studies to assess the phenotypic variabilities in the mango fruit varieties would be useful indicators for postharvest quality determination.

5 Conclusion

This study showed that variety and ripening period had an impact on the postharvest qualities on mango fruit. Considering the high genetic variability of the mango varieties, additional investigations at the biochemical and molecular levels are recommended to provide a more complete picture of what occurs at ripening. Besides understanding ripening behavior, it would be beneficial to integrate the results of this study with additional investigations that also take into consideration different harvesting times, location and postharvest storage conditions. Such information will provide an insight into the development of postharvest management strategies towards mango fruit quality improvement and open new marketing opportunities to the farmers and the local industry. Multivariate analysis has shown to be a valuable tool in making decisions and view variable/variety interrelations, thus facilitating mango selection and utilization strategy. Consumer perception for the fruit is an important factor that influences the marketability of fruits such as mango. As such, further investigation on these mango varieties aiming at the evaluation of their sensory properties will provide valuable information which could be used by growers, plant breeders, exporters and marketing agents to facilitate increased utilization and export of varieties that would be acceptable by consumers globally. Nevertheless, the information provided in this study would likely to open up promising possibilities in the world market trade for Southeast Asian mangoes which are locally common but globally rare.

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Appendix Table 1: Comparison of postharvest quality attributes between Southeast Asian mangoes and globally traded mangoes.

Attribute	'Chokanan'	'Golden Phoenix'	'Water lily'	'Alphonso'	'Ataulfo'	'Haden'	'Keitt'	'Tommy Atkins'
Firmness (N)	12.67[a]	9.53[a]	7.50[a]	0.93[b]	7.84[c]/11.70[d]	8.82[c]	5.30[e]	5.88[c]
SSC (%)	16.80[a]	20.30[a]	18.55[a]	19.41[b]	18.84[c]/21.60[d]	13.87[c]	17.30[e]	19.54[c]
TA (%)	0.26[a]	0.19[a]	0.12[a]	0.01[b]	0.56[c]	0.10[c]	0.20[e]	0.18[c]
Hue*	89.63[a]	108.61[a]	103.30[a]		85.00[d]/89.80[c]	67.42[c]		89.88[c]
L*	63.78[a]	57.59[a]	57.97[a]	64.30[b]	59.31[c]/75.00[d]	57.80[c]		59.53[c]

Note: Subscript letters: (a) Data obtained from the present study; (b) Nambi *et al.*, 2015; (c) Nassur *et al.*, 2015; (d) Palafox-Carlos *et al.*, 2012; (e) Padda *et al.*, 2011