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Physico-chemical characteristics of *Morinda citrifolia* fruit during growth and maturation

[Perubahan sifat fizikal dan kimia buah mengkudu (*Morinda citrifolia*) semasa tumbesaran dan kematangan]

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Keywords: physico-chemical changes, *Morinda citrifolia*, growth, maturation, nutrients, minerals

Abstract

The physico-chemical changes of *Morinda citrifolia* fruit during growth and maturation were studied. The fruit took 15–16 weeks after fruit set to reach full maturity. Changes in skin colour began from the 12th week after fruit set. At this stage, the colour changed rapidly from light green to 60% yellowish-green, and finally to yellowish-white at full maturity. The fruits remained firm throughout the growth period, but softened suddenly at the 16th week. The moisture content was higher in the mature fruit. The titratable acidity and total soluble solid increased significantly ($p \leq 0.05$) as the fruit ripened. The fruit were rich in potassium throughout the growth period. They had substantial amounts of vitamin A, with the highest content at 11th and 12th weeks after fruit set. The ascorbic acid content was stabilized from the ninth week onwards, until the amount increased significantly ($p \leq 0.05$) at the 14th and 15th week after fruit set. The fruit contain essential vitamins and minerals at all stages of development. The levels of minerals such as Na, Ca, Fe, P, Mg and Zn were fluctuated during the growth period.

Introduction

Morinda citrifolia, or noni and locally known as mengkudu, is a member of madder family, Rubiaceae. The plant is native to tropical Asia and Australia, and is distributed throughout the Pacific region. The plant is an evergreen shrub or small tree that grows to about 4–8 m tall. Its angular branches bear short stalked, ovate leaves that are thick, shiny, dark green and deeply veined. The flowers, about 75–90 in numbers, are in ovoid to globose heads. Peduncles are 10–30 mm long and the calyx, a truncated rim. The corolla is white, five lobed, with a greenish-white tube, 7–9 mm long. The lobes are oblong deltate, approximately 7 mm long.

Morinda citrifolia flowers are perfect containing both male and female organs. The fruit is a multiple fruit which composed of numerous, fused, ripened ovaries, each derived from a separate white flower. Each section of hexagonal marking on the fruit represents the place where a flower was once attached. The fruit is about 5–10 cm long and has an unusual shape, ovoid,

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and is yellowish-white at full maturity (Morton 1992).

The fruit is used by people throughout the tropical regions of the world. The shiny green leaves are used by the Caribs as a poultice for wounds, rheumatic joints, fevers and headaches. The leaves are applied directly to the afflicted area to relieve pain. The mashed fruit may also be applied directly to the afflicted area, including deep cuts and broken bones. It is also reported to cure a variety of ailments ranging from arthritis, rheumatism, sores, boils, and even to eliminate head lice (Kepler 1984). Today, the traditional medicinal uses of the plant persist, and nutraceutical teas, juices and extracts are marketed in Hawaii and worldwide.

Morinda citrifolia is propagated either from seed or stem cuttings. The seeds are dark brown, oblong triangular, and have a conspicuous air chamber (Nelson 2001). They are buoyant and hydrophobic due to this air chamber and have a durable, water repellent and fibrous seed coat. The seed coat is very tough, relatively thick and covered with cellophane like parchment layers.

The plants begin to bear fruit about 9 months after planting. Fruit can be harvested at an early stage although they are then generally small and few. Fruit may be picked just before they begin to ripen fully and turn completely yellowish-white on the tree. The ripe fruits are fleshy, 5–10 cm long, about 3–4 cm in diameter, soft and fetid (Nelson 2001).

The fruit are rich in vitamins and essential minerals such as potassium, magnesium, phosphorous and zinc (Elkins 1998). Knowing the correct time to harvest the fruit is very important to obtain optimum quality of fruit in order to develop effective post-harvest handling, packaging and storage techniques prior to processing. The main objective of this study was to determine the physico-chemical changes during growth and maturation of the *M. citrifolia* fruit and the optimum time to harvest.

Materials and methods

Tagging of fruit

To obtain fruit at different stages of growth and development, tagging was done after fruit set (fruit were 2 cm in diameter). About 1,000 fruits were randomly tagged from 80 trees at MARDI Kundang, Selangor, and allowed to grow until the fruit reached full maturity. Physical and chemical changes were observed at weekly intervals. The physical changes of the fruit such as length, diameter and weight were measured weekly in the field.

A total of 30 fruits were harvested randomly on a weekly basis from 80 different trees. The experiment was replicated three times, and 10 fruits per replicate were analysed weekly for chemical and physical analyses. Chemical analysis such as titratable acidity, total soluble solids, pH, nutrient and mineral analyses were conducted directly after harvest.

Physical analysis

Physical measurements on the fruit such as length, diameter and weight, as well as colour were done directly after harvest. Each measurement was performed on three replicates with 10 fruits per replication. Length and diameter were measured by using a Mitutoyo digital vernier caliper. The weight of fruit was measured by a top pan digital balance (Scaltex-SB 4000).

Skin colour was measured using a Minolta chromameter (CR 300) with the chromaticity planes defined by the dimensions L*, a* and b*. In this colour space, L* indicates lightness, while a* and b* are the chromaticity coordinates in which +a* is the red direction, –a* is the green direction, +b* is the yellow direction, and –b* is the blue direction. The chroma (C*) which indicates the intensity of the colour was also calculated using the formula $C^* = \sqrt{(a^2 + b^2)}$. Colour of the fruit can be expressed as a Hue angle, and can be calculated by using this formula: $\tan^{-1}$ (b/a) (Anon. 1994).

Firmness of the fruit was determined subjectively according to the method described by Miller and McDonald (1999) and Proulx et al. (2005). Ten fruits per replicate were used based on the whole fruit resistance to a slight applied finger pressure, and recorded using a 1 to 5 tactile rating scale where 1 = Very firm to the touch, very hard fruit with no response to finger pressure; 2 = Firm to the touch, substantial resistance to finger pressure; 3 = Moderate signs of softness, moderate resistance to finger pressure; 4 = Soft to the touch, slight resistance to finger pressure; and 5 = Very soft to the touch, does not offer any resistance to finger pressure.

Proximate analysis

Moisture content of the 30 fruits in triplicate were determined by using the method of AOAC (1990). The fruit were ground as fine as possible or homogenized in a blender (laboratory waring blender, model 5011). The homogenized sample of 5 g was placed in a 105 °C hot air convection oven (Mermert ULM 800) for moisture content analyses. Moisture content was obtained after the sample reached constant weight.

Protein, fat, ash and ascorbic acid (vitamin C) were determined according to methods of AOAC (1984) and Tee et al. (1986). Protein content was determined by weighing 0.2 g sample of blended fruit into a Kjeldahl digestion flask of capacity 30–35 ml. Potassium sulphate (1.2 g), mercuric solution (1 ml) and concentrated sulphuric acid (2.5 ml) were added. The mixture was then heated on a top pan heater in a fume cupboard. After heating, 10 ml of alkali mixture was added, and the steam was passed through the apparatus until the volume of liquid was 50–100 ml. Finally, the liquid was titrated with 0.02 N HCl.

In the method described by Tee et al. (1986), fat content was determined by directly extracting 10–40 g of dried ground sample of homogenized fruit with 150 ml petroleum ether in a Soxhlet extraction apparatus. The residue in the extraction flask after solvent removal represented the fat content of the sample.

The ash content was determined by drying the sample in a dish in an oven at 130 °C for 24 h. The dried sample was charred until it ceased smoking. The dish was placed in a cold muffle oven until the temperature reached 550 °C. Total ash content was obtained after the weight of the sample was constant. Total dietary fibre was analysed using a Tecator fibertech system E according to Lee et al. (1993).

Chemical analysis

The pH value was measured by using a pH meter (HANNA Instrument – model pH 211). The percentage of total soluble solids (TSS) was measured by using a refractometer (ATAGO DBX 55). The total titrable acidity (TTA) was determined from a sample of extracted juice by titration with an alkaline solution (0.1 N NaOH) until pH 8.1 (Askar and Treptow 1993).

Nutrient and vitamin analyses

Carbohydrate content was calculated by difference [100 – (moisture + protein + fat + dietary fibre + ash)]. Vitamin A was analysed by high performance liquid chromatography (Waters LC Module 1 Plus) according to Khatijah (2001). Vitamin C was determined by extracting the blended fruit with an aqueous solution of metaphosforic acid and acetic acid mixture (15 g metaphosforic acid + 40 ml acetic acid + 200 ml water) and titrated with 2,6 dichlorophenolindophenol dye. The end point of titration was detected when the dye gave a rose pink colour in acid solution (Tee et al. 1986).

Mineral analysis

Minerals content such as Na, Ca, K, Fe, P, Mg and Zn were determined by pre-treating the samples by dry ashing at 550 °C and dissolving them in nitric acid before injection into an inductive coupled plasma emission spectrophotometer (ICP) (Khatijah 2001).

Statistical analysis

The data were statistically analysed using Statistical Analyses System Version 6.07 for analysis of variance (ANOVA). Duncan Multiple Range Test was used as the test of significance in the differences among means.

Results and discussion

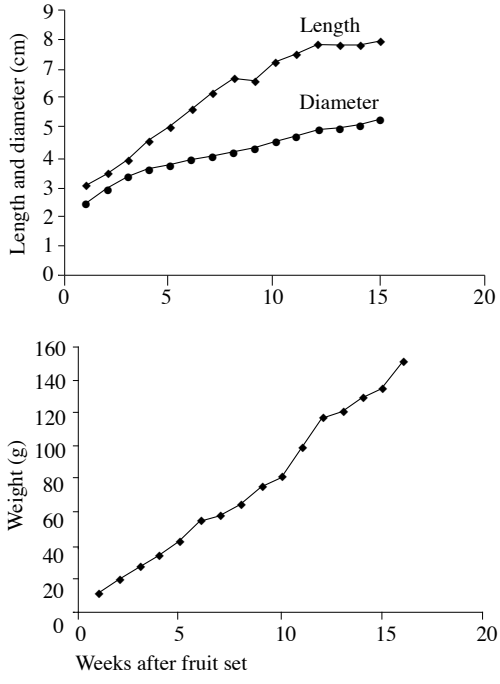
Changes in physical attributes

During growth, the length, diameter and weight of *M. citrifolia* fruit showed a steady increase (*Figure 1*). The weight increased from 10 g/fruit in the first week after fruit set (AFS) to 150 g/fruit at full maturity. This was due to cell enlargement and cell division of the internal structure (Wills et al. 1998). The fruit took about 15–16 weeks AFS to mature (2 cm in diameter). At maturity, the skin colour changed to yellowish-white with the length and diameter at about 8 cm and 5 cm respectively.

The fruit was green in colour from the first week AFS. Changes in colour were seen at 11th week AFS. At this stage, the skin colour changed from light green (11th week AFS) to 60% yellowish-green (12th week AFS). The colour changed further from 70–80% yellowish-green to 70% yellowish-white at the 13th week and 14th week AFS respectively. At 15th and 16th week AFS the skin colour changed to 90–100% yellowish-white.

The changes in skin colour increased over time as the fruit ripened as shown by the overall significant increases in the L*, a* b*, C*and Hue angle (°) values (*Table 1*). Fruit harvested at week 1 to week 8 AFS were green in colour. At 9th week AFS and onwards, the mature fruit harvested were yellowish-white. Hue angle (°) increased in *M. citrifolia* fruit during ripening from 60° to 69.8° which indicated colour changes from dull green to yellowish-white. Fruit lightness (L) and chroma (C*) increased as the fruit ripened, which reflected the lighter and more vivid colours (*Table 1*).

The seed colour began to change to 100% reddish-brown from 12th week AFS (*Table 2*). The fruit texture remained firm



The values were expressed as means ± standard deviation of three replicates (10 fruits replicate)

Figure 1. Changes in length, diameter and weight of ***Morinda citrifolia*** *fruit after fruit set*

throughout the 15 week growth period but fruit firmness suddenly softened at the 16th week AFS (*Table 2*). The moisture content of the fruit increased significantly from 86.6% (9th week) to 88.1% (15th week) as shown in *Table 3*.

Chemical changes during growth and maturation

The chemical contents of the fruits were analysed from 9th week AFS onwards based on the commercial reception of maturity as the fruit are not harvested any earlier. According to common practice, the fruit are harvested at the mature green stage and when 75% yellowish-white.

The chemical properties such as total soluble solids (TSS) and total titratable acidity (TTA) increased significantly at $p \leq 0.05$ as the fruit ripened (*Table 4*). TSS increased from 6.22 ± 0.35 ºBrix (10th week AFS) to 8.3 ± 0.55 ºBrix (16th week

Table 1. Changes in L*, a*, b*, C* and hue angle (°) of *Morinda citrifolia* fruit after fruit set

Week	L*	a*	b*	C*	Hue angle (°)
1	52.8 ± 2.98e	–19.35 ± 1.08ef	34.05 ± 2.19cd	39.32 ± 2.26bc	60.39e
2	53.5 ± 2.08ef	–19.85 ± 1.46ef	33.95 ± 1.68cd	39.44 ± 1.94bc	59.09e
3	54.27 ± 1.56e	–18.64 ± 1.70ef	33.55 ± 1.52cd	39.08 ± 1.87c	60.94e
4	51.98 ± 1.40ef	–17.04 ± 1.04cd	26.25 ± 1.60f	31.3 ± 1.90f	57.01f
5	50.89 ± 1.81f	–17.94 ± 1.73de	27.33 ± 1.70f	32.71 ± 1.87ef	56.72f
6	52.95 ± 2.34ef	–18.44 ± 1.88def	30.44 ± 1.85e	35.62 ± 2.10d	58.79ef
7	53.45 ± 1.87ef	–18.11 ± 0.92de	30.09 ± 1.48e	35.92 ± 1.56d	58.95ef
8	52.8 ± 2.12ef	–17.75 ± 0.97f	30.28 ± 1.95e	35.12 ± 1.87de	59.62e
9	58.56 ± 1.68d	–20.51 ± 0.75f	36.29 ± 1.19b	30.21 ± 1.10f	60.53e
10	58.34 ± 2.97d	–19.69 ± 1.27ef	35.2 ± 1.10bc	40.36 ± 1.10abc	60.78e
11	60.56 ± 2.98d	–19.41 ± 1.47ef	37.08 ± 2.18ab	41.91 ± 0.87ab	62.37d
12	63.5 ± 2.72c	–18.17 ± 2.20de	36.34 ± 3.25b	40.63 ± 1.21abc	63.43cd
13	67.47 ± 2.66b	–13.51 ± 1.93ab	36.68 ± 3.99b	39.11 ± 1.28c	69.78a
14	69.22 ± 2.20a	–12.89 ± 2.03a	32.01 ± 4.36de	34.51 ± 4.75de	68.07a
15	74.1 ± 4.65a	–16.68 ± 1.92 cb	39.18 ± 4.98a	42.6 ± 5.47d	66.94b
16	71.15 ± 3.60a	–14.77 ± 2.51ab	31.12 ± 4.52c	34.48 ± 4.98de	64.61c

The values were expressed as mean ± standard deviation of three replicates (10 fruits/replicate)
Means with the same letter within each column are not significantly different from one another at $p \leq 0.05$

Table 2. Skin colour, seed colour and firmness rating scale of *Morinda citrifolia* fruit after fruit set during growth and maturation

Week	Skin colour	Seed colour	Firmness rating scale
1	Green	White	1
2	Green	White	1
3	Green	White	1
4	Green	White	1
5	Green	White	1
6	Green	White	1
7	Green	Light brown	1
8	Green	Light brown	1
9	Light green	Light brown	1
10	Light green	80–95% dark brown	1
11	Light green	90–95% dark brown	1
12	60% yellowish-green	100% dark brown	1
13	70–80% yellowish-green	100% dark brown	1
14	70% yellowish-white	100% dark brown	1
15	90% yellowish-white	100% dark brown	1
16	100% yellowish-white	100% dark brown	3

1 = Very firm to the touch, very hard fruit with no response to finger pressure
3 = Moderate signs of softness, moderate resistance to finger pressure

AFS). Similar findings were also reported by Rodriguez et al. (1971) and Bashir and Abu-Goukh (2003) for guava. The TSS in guava increased as the fruit ripened. The same observations were reported for date (Dowson and Aten 1962), mango (Minessy et al. 1984; Abu-Goukh and Abu Sarra 1993) and banana (Ibrahim et al. 1994). Biale (1960) attributed the increase in TSS during fruit ripening due to hydrolysis of starch to sugar.

The TTA which presented the percentage of citric acid per 100 g

Table 3. Proximate and vitamin composition of 100 g *Morinda citrifolia* fruit during growth and maturation

Week	Moisture (g)	Protein (g)	Fat (g)	Dietary fibre (g)	Carbohydrate (g)	Ash (g)	Vitamin A (µg, R.E.)	Vitamin C (mg)
9	86.58 ± 0.20b	1.09 ± 0.12a	0.12 ± 0.02a	10.74 ± 0.49a	0.44e	1.03 ± 0.06b	17.33 ± 1.53c	4.58 ± 0.12b
10	87.21 ± 0.32c	1.06 ± 0.04a	0.09 ± 0.02b	8.77 ± 0.29b	1.68c	1.19 ± 0.01a	31.00 ± 2.18b	4.32 ± 0.13b
11	87.04 ± 0.14c	0.91 ± 0.06b	0.10 ± 0.02ab	9.77 ± 0.52a	1.13c	1.05 ± 0.06b	57.00 ± 2.57a	4.75 ± 0.32b
12	87.10 ± 0.26c	0.80 ± 0.11c	0.09 ± 0.01b	6.84 ± 0.05c	4.34a	0.83 ± 0.06c	50.00 ± 4.00a	4.57 ± 0.35b
13	87.55 ± 0.42b	0.57 ± 0.07d	0.19 ± 0.02ab	8.67 ± 0.12cd	2.20b	0.82 ± 0.03c	5.67 ± 2.08d	4.55 ± 0.65b
14	88.06 ± 0.34a	0.59 ± 0.06d	0.08 ± 0.07b	10.15 ± 0.39ad	0.48e	0.64 ± 0.04d	4.33 ± 1.15d	6.71 ± 0.10a
15	88.10 ± 0.23a	0.56 ± 0.06d	0.08 ± 0.01b	9.63 ± 0.21ad	0.60d	1.03 ± 0.05b	4.67 ± 1.53d	6.82 ± 0.01a

The values were expressed as means ± standard deviation of three replicates (10 fruits/replicate)
Means with the same letter within each column were not significantly different from one another at $p \leq 0.05$

(Wills et al. 1998) increased from 0.22% (10th week AFS) to 0.34% (16th week AFS). Similar results were reported during the ripening of mango (Abu-Goukh and Abu Sarra 1993), banana (Desai and Deshpande 1975; Ahmed and Tingwa 1995) and guava (Bashir and Abu-Goukh 2003).

Increase in TTA probably corresponded to increase in total organic acids such as citric acid, quinic acid, oxalic acid and malic acid during fruit ripening as reported by Albertini et al. (2006). The Brix to total titratable acidity ratio increased from 12th to 14th week AFS with the ratio varying 31.86–33.07. The ratio can be used to indicate sweetness (Askar and Treptow 1993).

Proximate composition of the fruit such as fat and ash content were found to be fluctuated throughout the experiment (*Table 3*). Protein content decreased significantly ($p \leq 0.05$) from 1.1 mg/100 g (9th week AFS) to 0.6 mg/100 g (15th week AFS). This decline was probably due to the breakdown of protein molecules during senescence, which supports the view that proteins in ripening fruit are enzymes required for the ripening process (Frenkel et al. 1968). Carbohydrate content was observed to be highest at 12th week AFS (4.34 g/100 g).

The fruit had substantial amounts of vitamin A with higher amounts at the 11th and 12th week AFS (*Table 3*). However, the amount of vitamin C stabilized at 4.6–4.8 mg/100g from the 9th week onwards, but the amount increased slightly to 6.7 and 6.8 mg/100 g at the 14th and 15th week AFS respectively (*Table 3*).

The mineral contents of the fruit, analysed from the 9th week AFS and onwards, were not significantly different during its growth and maturation, and the trend in the differences were not consistent (*Table 5*). The fruit was rich in potassium (403.25 mg/100 g) at the 13th week AFS but the amount decreased at 14th to 15th week AFS (380.4 to 369.9 mg/100 g).

Table 4. Changes in total soluble solid (TSS), titrable acidity (TTA), pH and Brix/TTA of fruit after fruit set during growth and maturation

Week	TSS (°Brix)	TTA (%)	pH	Brix/TTA
9	6.13 ± 0.29d	0.22 ±0.02b	4.29 ± 0.04a	28.10abc
10	6.22 ± 0.35d	0.22 ± 0.01b	4.36 ± 0.10a	28.40abc
11	6.94 ± 0.30c	0.27 ± 0.02b	4.29 ± 0.01ab	26.0abc
12	7.98 ± 0.46ab	0.26 ± 0.06b	4.29 ± 0.01ab	30.2ab
13	7.20 ± 0.47bc	0.23 ± 0.03b	4.29 ± 0.06ab	31.86a
14	7.64 ± 0.10ab	0.23 ± 0.02b	4.15 ± 0.02c	33.07a
15	7.94 ± 0.14ab	0.36 ± 0.03a	4.19 ± 0.01c	21.80c
16	8.30 ± 0.56a	0.34 ± 0.03a	4.22 ± 0.03c	24.3bc

The values were expressed as means ± standard deviation of three replicates (10 fruits/replicate)
Means with the same letter within each column are not significantly different from one another at $p \leq 0.05$

Similar findings were reported in berry fruit in which potassium concentration began to increase from 9 to 13 weeks AFS and plateaued from 13th weeks onwards (Davies et al. 2006). These findings might be due to cell division and expansion during fruit development for which potassium plays an important role as a sugar transporter in the cell vacuole during the early stages of fruit development, but as the fruit ripened, potassium may play a secondary role in sugar transportation (Davies et al. 2006). This means that as the fruit attained full maturity, the potassium concentration either decreased or stabilized (Ferguson 2001).

The amount of sodium decreased from 8.05 mg/100 g (9th week AFS) to 3.52 mg/100 g (15th week AFS). Similar results were observed for calcium. The amount of calcium decreased from 45.62 mg/100 g (9th week AFS) to 38.08 mg/100 g (15th week AFS) as the fruit ripened (*Table 5*). The same was observed in apple (Ferguson 2001), in which the movement of calcium into the developing apple fruit was rapid in the early stages of growth but fell off, with there being little or no increase in calcium content in the fruit over the later stages of growth. This difference was due to calcium accumulations in the flesh which was reflected by increasing fruit size as the fruit matured (Ferguson 2001).

The levels of other minerals such as iron and zinc did not vary very much during the growth period studied (9–15 weeks). The values remained constant from 9th week onwards (0.3–0.46 mg/100 g for iron and 0.11–0.26 mg/100 g for zinc). Similar results were found for phosphorus and magnesium content with the values varying 17.02–19.57 mg/100 g (*Table 5*). Analysis of copper content indicated that the mineral was not present at all in *M. citrifolia* fruit during its growth.

Conclusion

Fruit maturity is very important for the *Morinda citrifolia* processor. Therefore, the fruit need to be harvested at the correct stage of maturity for the purpose of processing. Some processors prefer to harvest the fruit green due to the ease of slicing such fruit using mechanical slicer and drying compared to the ripe fruits, as the fruit did not bleed excessive juice over the equipment. So, the green fruit are recommended for harvest at the 11th and 12th week AFS when they had the highest content of vitamin A.

The green fruit are suitable for processing into tablets and beverage powders. The juice processors prefer to harvest the fruit at the fully ripe yellow stage, when the fruit is juicy and soft. Thus, the ripe fruit is recommended to be

Table 5. Mineral content of 100 g *Morinda citrifolia* fruit during growth and maturation

Weeks	Na (mg)	Ca (mg)	K (mg)	Fe (mg)	P (mg)	Mg (mg)	Zn (mg)
9	8.05 ± 1.81a	45.62 ± 4.13a	359.25 ± 14.00c	0.42 ± 0.09a	18.95 ± 1.14a	19.50 ± 0.81a	0.11 ± 0.02ac
10	5.40 ± 1.28b	39.85 ± 4.74bc	382.4 ± 8.36ab	0.35 ± 0.08a	18.41 ± 0.31a	18.13 ± 0.41ab	0.11 ± 0.03ac
11	4.60 ± 0.56bc	42.10 ± 2.96ac	399.60 ± 10.11ad	0.30 ± 0.04a	18.89 ± 0.37a	19.04 ± 0.39a	0.10 ± 0.02c
12	3.55 ± 1.31c	39.14 ± 3.53b	322.49 ± 9.29f	0.39 ± 0.07a	15.48 ± 1.20b	16.32 ± 0.46c	0.16 ± 0.05ace
13	5.09 ± 0.77b	37.36 ± 3.55bd	403.25 ± 11.71a	0.43 ± 0.05a	19.64 ± 1.30a	19.22 ± 0.76a	0.16 ± 0.06ace
14	4.95 ± 0.70b	36.51 ± 3.94bd	380.43 ± 12.51abd	0.53 ± 0.01b	18.39 ± 1.14a	17.02 ± 0.73b	0.22 ± 0.05ad
15	3.52 ± 0.90c	38.08 ± 3.25bc	369.93 ± 12.80ce	0.46 ± 0.10a	19.57 ± 1.25a	17.40 ± 0.47b	0.26 ± 0.02ade

The values were expressed as means ± standard deviation of three replicates (10 fruits/replicate)
Means with the same letter within each column were not significantly different from one another at $p \leq 0.05$

harvested at 14th to 15th week AFS when the vitamin C content is still at a higher level.

Based on this study, it can be concluded that the harvest indices of *Morinda citrifolia* fruit greatly depends on market demand and usage because of different processing requirements for different products. The fruit contain essential vitamins and minerals at all stages of development. Thus, the fruit has a great potential to be extracted, processed and commercialized into health products which may be used as a nutrient supplement to the diet.

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References

Abu-Goukh, A.A. and Abu Sarra, A.F. (1993). Compositional changes during mango fruit ripening. *University of Khartoum Journal of Agricultural Sciences* 1(1): 33–51

Ahmed, O.K. and Tingwa, P.O. (1995). Effect of gibberellic acid on several parameters of ripening banana fruit. *University of Khartoum Journal of Agricultural Sciences* 3(1): 47–59

Albertini, M.V., Carcouet, E., Pailley, O., Gambotti, C., Luro, F. and Berti, L. (2006). Changes in organic acids and sugars during early stages of development of acidic and acidless citrus fruit. *J. Agric. Food Chem.* (54): 8335–8339

Anon. (1994). Minolta – Precise colour communication, p. 46–49. Minolta Co. Ltd. Osaka, Japan

AOAC (1984). *Official methods of analysis*. 14th ed. (Williams, S., ed.). Arlington, VA: Association of Official Analytical Chemists

—— (1990). *Official methods of analysis*. 15th ed. Arlington, VA: Association of Official Analytical Chemists

Askar, A. and Treptow, H. (1993). *Quality assurance in tropical fruit processing,* p. 25. Berlin: Springer–Verlag Berlin Heidelberg Publication

Bashir, H.A. and Abu-Goukh, A.A. (2003). Compositional changes during guava fruit ripening. *Food Chemistry* (80): 557–563

Biale, J.B. (1960). The post harvest biochemistry of tropical and sub-tropical fruits. *Advances in Food Research* (10): 293–394

Davies, C., Shin, R., Liu, W., Thomas, M.R. and Schachtman, D.P. (2006). Transporters expressed during grape berry (*Vitis vinifera* L.) development are associated with an increase in berry size and berry potassium accumulation. *Journal of Experimental Botany* 57(12): 3209–3216

Desai, B.B. and Deshpande, P.S. (1975). Chemical transformation in three varieties of banana fruits stored at 20 °C. *Mysore Journal of Agricultural Science* (9): 634–636

Dowson, V.H. and Aten, A. (1962). *Dates handling, processing and packing,* (Plant production and protection series no. 13). Rome: Food and Agriculture Organization of the United Nations

Elkins, R. (1998). *Hawaiian noni* (*Morinda citrifolia*), 5–27 p. Salt Lake City, UT: Woodland Publishing

Ferguson, I. (2001). Calcium in apple fruit. *Proceedings of Washington tree fruit postharvest conference*. 13–14 Mar. 2001, Wanatchee, Washington, p. 1–4. WSU-TFREC Postharvest Information Network

Frenkel, C., Klein, I. and Dilley, D.R. (1968). Protein synthesis in relation to ripening of pome fruits. *Plant Physiology* 43: 1146–1153

Ibrahim, K.E. Abu-Goukh, A.A. and Yusuf, K.S. (1994). Use of ethylene, acetylene and ethrel on banana fruit ripening. *University of Khartoum Journal of Agricultural Science* 2(1): 79–92

Kepler, A.K. (1984). *Hawaiian heritage plants*, p. 145–150. Honolulu: The Oriental Publishing Company

Khatijah, I. (2001). Dietary fibre, vitamin A and ascorbic acid content of Malaysian vegetable dishes. *Proc. conference on functional food*, (Theme: Latest development), 10–11 Apr. 2001, Putrajaya, p. 99–105. Serdang: UPM, CSIRO and NBD

Lee, S.C., De Vries, J.W. and Sullivan, D.M. (1993). Total, soluble and insoluble dietary fiber in foods. In: *Methods of analysis for nutrition labelling* (Sullivan, D.M. and Carpenter, D.E., eds.), p. 210–213. Arlington, VA: AOAC International

Miller, W.R. and McDonald, R.E. (1999). Irradiation, stage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 34: 1112–1115

Minessy, F.A., Saeed, A.R. and El-Rayah, A. (1984). Respiration and chemical changes associated with ripening of mango fruit (*Mangifera indica* L.). *Sudan Agricultural Journal* 10: 103–111

Morton, J. (1992). The ocean going noni, or indian mulberry (*Morinda citrifolia*, Rubiaceae) and some of its colorful relatives. *Economic Botany* 46(3): 241–256

Nelson, S.C. (2001). *Noni cultivation in Hawaii*. In: *Fruits and nuts*. Manoa, HI: College of Tropical Agriculture & Human Resources, University of Hawaii

Proulx, E., Cecilia, M., Nunes, N., Emond, J.P. and Brecha, J.K. (2005). Quality attributes limiting papaya postharvest life at chilling and non-chilling temperatures. *Proc. Fla. State Hort. Soc.* 118: 389–395

Rodriguez, R., Agarwal, P.C. and Saha, N.K. (1971). Biochemical changes during development of "Safeda" guava fruit. *Indian Food Packer* 25(1): 5–20

Tee, E.S., Siti Mizura, S., Kuladevan, R., Young, S.I., Khor, S.C. and Chin, S.K. (eds.) (1986). *Laboratory procedures in nutrient analysis of foods,* p. 1–2, 5–16, 20–2, 31–54, 63–81. Kuala Lumpur: IMR

Wills, R., McGlasson, B., Graham, D. and Joyce, D. (1998). Postharvest. In: *An introduction to the physiology & handling of fruits, vegetables & ornamentals,* p. 33–37. Sydney: University of New South Wales Press

Abstrak

Perubahan sifat fizikal dan kimia buah mengkudu (*Morinda citrifolia*) semasa tumbesaran dan kematangan telah dikaji. Buah mengkudu mengambil masa selama 15–16 minggu selepas berputik untuk masak. Perubahan warna kulit bermula pada minggu ke-12 selepas berputik. Pada peringkat ini, buah cepat berubah warna daripada kehijauan kepada 60% hijau kekuningan dan seterusnya putih kekuningan apabila buah masak. Tekstur buah didapati tegar semasa pertumbuhan tetapi lembut pada minggu ke-16 selepas berputik. Peratus lembapan buah didapati tinggi di dalam buah yang matang. Peratus keasidan dan kandungan pepejal larut buah meningkat dengan ketara ($p < 0.05$) apabila buah masak. Buah mengkudu mengandungi mineral kalium yang tinggi sepanjang proses tumbesaran. Buah ini juga mempunyai kandungan vitamin A yang paling tinggi pada minggu ke-11 dan ke-12 selepas berputik. Kandungan asid askorbik didapati stabil dari minggu ke-9 dan meningkat secara ketara ($p < 0.05$) pada minggu ke-14 dan minggu ke-15 selepas berputik. Buah mengkudu mengandungi vitamin dan mineral pada setiap peringkat kematangan. Kandungan mineral seperti Na, Ca, Fe, P, Mg dan Zn tidak konsisten sepanjang proses tumbesaran.

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