International Food Research Journal 21(4): 1659-1665 (2014)
Journal homepage: http://www.ifrj.upm.edu.my

Changes in fruit quality and volatile flavor compounds during on-tree maturation of longkong

[1]Sangkasanya, S., [2]Lertsiri, S. and [*1]Meenune, M.

[1]*Faculty of Agro-Industry/Postharvest Technology Innovation Center, Prince of Songkla University, Hat-Yai, Songkhla 90112, Thailand*
[2]*Department of Biotechnology, Faculty of Science, Mahidol. University, Bangkok 10400, Thailand*

Article history

Received: 12 December 2013
Received in revised form: 23 February 2014
Accepted: 2 March 2014

Keywords

Longkong
On-tree maturation
Quality
Volatile
Flavor

Abstract

Longkong (*Aglaia dookkoo* Griff.) is a non-climacteric fruit, juicy with typically aromatic smell and sweet but slightly sour taste. The optimal harvest period was started from 13 to 15 weeks after anthesis. The physical and chemical qualities of longkong at different stages of on-tree maturation were evaluated as follows: ripe (13 weeks after anthesis); medium ripe (14 weeks after anthesis); and full ripe (15 weeks after anthesis). It was found that longkong became light to bright yellow with the stages of maturation ($p < 0.05$). This can be indicated by the highest lightness ($L^* = 64.21$) and yellowness ($b^* = 34.37$) values shown in longkong at the full ripe stage. Moreover, the texture changed and softened with maturation ($p < 0.05$). The fruit size and weight increased with the stage of maturity but there was no significant difference ($p < 0.05$). The fruit were in the range of 3.17-3.30 cm in diameter and 19.94-21.36 g in weight. The moisture content was slightly increased with the stage of maturity ($p < 0.05$). During on-tree maturation, from the ripe to full ripe stages, acidity and organic acids (citric, maleic and malic acids) decreased while pH, TSS and total sugar content increased. The main sugars found in longkong were sucrose, glucose and fructose, respectively. From the ripe to medium ripe stages of longkong maturation, the sucrose content slowly increased from 9.88% to 11.44%. However, during the full ripe stage the sucrose content was 7.03% ($p < 0.05$). The glucose content significantly decreased from 1.98% to 1.46% during the ripe to medium ripe stages of the maturing longkong and then it increased again to 2.92% at the full ripe stage ($p < 0.05$). Similarly to fructose content, it also decreased from 2.76% to 2.20% during the ripe to medium ripe stages of the maturing longkong. After that it increased again to 3.39% at the full ripe stage ($p < 0.05$). The green aroma of 1-hexanol was the only volatile compound which was found in ripe longkong. From the ripe to full ripe stages, the longkong had more fruity and sweet characteristics. There were many terpenes and their derivatives. The key volatile flavor compounds were d-germacrene and 3-hydroxy-2-butanone. They had herbaceous and sweet attributes.

Introduction

Longkong (*Aglaia dookkoo* Griff.), is a well known and important commercial fruit grown in southern Thailand. It belongs to the *Meliaceae* family and has its origin in the South of Thailand, Indonesia, the Philippines and the Malau Islands (Paull, 2004). The demand for this fruit has increased tremendously. This is because this fruit is juicy, has a pleasant taste and contains a variety of nutrients. The Office of Agricultural Economics (2009) reported that farm values of longkong increased from 4,521 in the year 2000 to 5,092 million baht in the years 2007. However, the farm values of longkong have decreased to 3,000 million baht in the year 2013. It was probably due to the insurgency in the south of Thailand. Longkong is a non-climacteric tropical fruit, which comes in racemes. The fruit is round; roughly 3-4 cm across and soft. It has a smooth, thin and bright yellow skin. There are 15-20 fruits per raceme, and are almost seedless and free of latex. Longkong pulp is white, juicy with a typically aromatic smell and a sweet but slightly sour taste (Sabah, 2004; Paull, 2004). Normally, physical or chemical qualities such as color changes, acidity changes and total soluble solid (TSS) changes can be used as a harvesting index for longkong (Pantuvanid, 1985; Bumrugrak, 1992). The ripe stage (13-15 weeks after anthesis) is the optimal stage for harvesting. The fruit skin becomes a full bright yellow and its flesh becomes transparent and it has typical aromas and a sweet taste (Bumrugrak, 1992).

In addition, the National Bureau of Agricultural Commodity and Food Standards (2006) reported that the characteristics of longkong at the full ripe stage should be a full bright yellow skin color, soft

*Corresponding author.
Email: *mutita_meenune@yahoo.co.uk*
Tel: 66 7428 6335 Fax: 66 7455 8866

flesh and 15ºBrix of total soluble solid. The chemical constituents that affect the organoleptic profiles and characteristic of fruit flavors are the important quality standards for fresh fruit. Sweetness is related mainly to types and concentrations of sugars. Organic acids mainly contribute to the sourness. During maturation, sugars increase and organic acids decline. This makes the fruit much sweeter (Wills *et al*., 1998; Vendramini and Trugo, 2000; Sapii *et al.*, 2000; Soares *et al.*, 2007). Volatile flavor compounds mainly contribute to the fruity aroma and are synthesized during the maturation of the fruit. The unique flavor characteristic of longkong seems to directly influence the demand for this fruit. However, the formation of the flavor profile in longkong during on-tree maturation has not yet been investigated. Therefore, this study was undertaken to establish the changes in longkong quality, in physical or chemical qualities and volatile flavor compounds, during on-tree maturation.

Materials and Methods

Chemicals

The D-glucose, D-fructose, sucrose were purchased from Fluka (Messerchmittstr, Switzerland). Acetonitrile and water (HPLC grade) were obtained from Prolabo (Paris, France). Sodium hydroxide, copper sulfate pentahydrate, trichloroacetic acid and sodium sulfite were obtained from Merck (Darmstadt, Germany). Potassium sodium tartrate, lead acetate and potassium oxalate were obtained from Riedel-deHaen (Seelze, Germany). Dichloromethane was obtained from LabScan Asia Co., Ltd (Bangkok, Thailand).

Plant material

Longkong was obtained from a contact garden in Natawee district (Songkhla province, Thailand). It was harvested at different stages of on-tree maturation; at 13 (ripe), 14 (medium ripe) and 15 (full ripe) weeks after anthesis. Fruit was harvested in the morning and immediately transported on the same day to the Food Analysis laboratory, Faculty of Agro-Industry (approximately 2 hours). Fruits free from any apparent skin damage and uniform size (grade A about 3-3.5 cm in diameter, according to Tanyongmut market) were selected for analysis.

Fruit quality evaluation

Both physical (fruit color, fruit firmness, fruit size and fruit weight) and chemical (total soluble solid; TSS, sugars (reducing sugars, total sugars and type and concentration of sugars, titratable acidity; TA, pH, moisture content, type and concentration of organic acids and volatile flavor compounds) qualities were evaluated. For chemical quality analysis, the homogenate was prepared for analysis. It was prepared by flesh (de-seeded) blending at constant speed, using a blender for 3 min at 4°C. After that, it was filtered through the stainless steel sieve, yielding the homogenate. For physical quality analysis, the fruit was cut-off raceme forming of individual fruit. The 10 individual fruits were used to measure in each quality.

Fruit color

Color changes on two opposite sides of fruit skin were quantified in term of CIE Lightness (L^*), Redness (a^*) and Yellowness (b^*) values using a Color Flex, Hunter Lab colorimeter. CIE values were calculated in terms of Hue (h°) angle = artangent b^*/a^* and Chroma (C^* value) = $(a^{*2}+b^{*2})^{1/2}$ (Apai, 2010).

Fruit firmness

Fruit firmness on two opposite sides of fruit was measurement using a TA-XT2i Texture Analyzer (Stable Micro System, UK) equipped with a 2 mm diameter cylinder probe (P/2) with penetrometric method. The results were expressed as gram force (Adapted from Sapii *et al.*, 2000).

Fruit diameter

Fruit diameter was measured by using a SV-02 Stainless Steel Dial Vernier Calipers.

Fruit weight

Fruit weight was evaluated by weighing by using a Sartorius BP310S analytical balance.

Moisture content

Moisture content was determined gravimetrically by drying at 105°C (A.O.A.C., 2000).

TSS

TSS was determined using an Atago 1E (Japan) hand refractometer at 25ºC and expressed as ºBrix.

Total and reducing sugars

Total sugar and reducing sugar content was quantified by titration with Fehling reagents according Lane and Eynon and Volumetric method (Adapted from Ong *et al*., 2006).

TA

TA was quantified by titrating 10 ml of the homogenate to an end point of pH 8.2 with 0.1 N NaOH with 1% (v/v) phenolphthaleine as an indicator. The result was calculated as percentage of citric acid

(Adapted from Ong *et al*., 2006).

pH

pH was measured using a Sartorius PB-20 (Germany) digital pH meter.

Types and concentrations of sugars

Types and concentrations of sugars (sucrose, fructose and glucose) were determined by HPLC (Shimadzu, CR 6A Chromatopac) with Hypersil APS-2 column (Thermo Scientific, USA). Injection volume was 10 µl with an isocratic flow rate 1 ml/min and refractive index detector. The 90% acetonitrile was used as a mobile phase. Their concentrations were quantified by comparing retention time and peak area of the samples with known standards (Adapted from Ong *et al.*, 2006).

Types and concentrations of organic acids

Organic acids (citric, maleic and malic acids) were determined by HPLC (Agilent 1100 series HPLC) with Hypersil ODS 4.0×250 mm, 5 µm reverse phase column (Thermo Scientific, USA). Injection volume was 10 µl with an isocratic flow rate 0.5 ml/min and diode array detector was set at 210 nm. Mobile phase was 0.05 disodium hydrogen phosphate, pH 2.5. Their concentrations were quantified by comparing retention time and peak area of the samples with known standards (Adapted from Chairgulprasert *et al*., 2006).

Volatile flavor compounds

Volatile flavor compounds were extracted by direct solvent extraction and identified by GC-MS. The 100 ml clear solution of longkong juice was mixed with 100 ml dichloromethane. The mixture was extracted for 90 min and left equilibrates for 30 min at room temperature (~30°C). Solvent phase was collected and sediment was re-extracted twice. The combined solvent phase was dried on anhydrous Na_2SO_4, kept over-night at -20°C, cold- filtered and concentrated by purging of nitrogen gas to produce the concentrate. The concentrate was kept at -20°C prior to analysis. The volatile flavor compounds were identified by GC-MS. A chromatograph Hewlet-Packard 6890 (Palo Alto, CA, USA) was used with HP-FFAP column (25 m×0.20 mm; film thickness 0.20 mm). The inlet temperature was set at 240°C and the column temperature was maintained at 40°C for 2 min, followed by an increase to 240°C at the rate of 5°C/min and held for 13 min. The carrier gas was applied by ultra high purity helium at a constant flow of 1.5 ml/min. A Hewlet-Packard 5973 A mass spectrometer with a quadrupole mass filter was coupled to the GC. A mass spectrum (MS) was obtained at 70 eV in the electronic impact (EI) and positive modes. MS was scanned in range m/z 40-350 at 1s intervals. The integration of peaks was done on HP chemstation software (Hewlett-Packard). The minimum peak area for detection level was 100,000 counts (Adapted from Wanakhachornkrai and Lertsiri, 2003).

Statistical analysis

The experiment was performed by completely randomized design (CRD). Significant differences between means were estimated by Duncan's new multiple range test (DMRT), with a level of significance of 0.05. Statistical analyses were performed by using the Statistical Package for Social Science (SPSS 6.0 for windows, SPSS Inc., Chicago, IL, USA).

Results and Discussion

The physical qualities (fruit color, firmness, size and weight) of longkong at three different stages of on-tree maturation (13 weeks (ripe), 14 weeks (medium ripe) and 15 weeks (full ripe) were evaluated. The results were reported and discussed as follows.

Physical quality

Fruit color

The data on fruit skin color were recorded and quantified in terms of CIE (lightness (L^*), redness (a^*) and yellowness (b^*) values. A high L^*, a^* and b^* values refer to lighter, more reddish and more yellowish surface color of longkong. Fruit skin color was found to differ significantly with the different stages of on-tree maturation ($p < 0.05$). It was found that the fruit skin at the ripe stage was pale yellow with a tinge of green, and the L^*, a^* and b^* values were 43.16, 3.69 and 23.36, respectively (Figures 1A, 1B and 1C). The L^* and b^* values increased significantly with on-tree maturation ($p < 0.05$). The significant increase in L^* value (L^* = 58.43) and b^* value (b^* = 23.95) ($p < 0.05$) was found when the fruit reached to the medium ripe stage (Figures 1A and 1B). In the full ripe stage, longkong was lighter and more yellow indicated with sharpen increased in L^* and b^* values. The L^* and b^* values were 64.21 and 34.37, respectively (Figure 1A and 1B). Changes in fruit skin color from pale yellow with tinge of green to bright yellowness could be explained by degrade of chlorophyll (Sapii *et al.*, 2000). However, the significant highest a^* value of 5.21 was observed in full ripe longkong (Figure 1C). This color refers

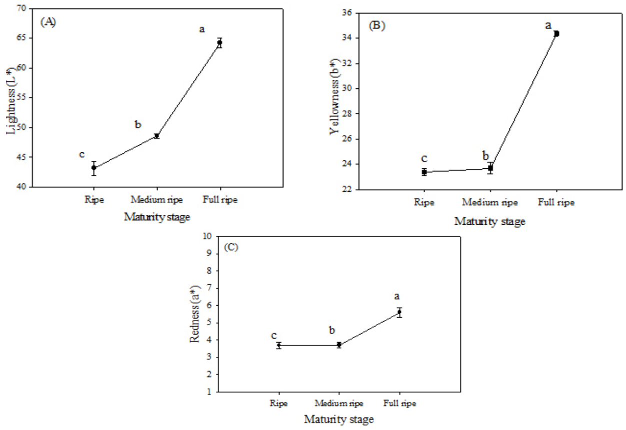

Figure 1. Lightness (A), yellowness (B) and redness (C) values in longkong skin at different stages of on-tree maturation

Note: Data are mean ± standard deviation (in fifteen replicates). Means with different superscript letters indicate that there are significant differences among maturity stages ($p < 0.05$).

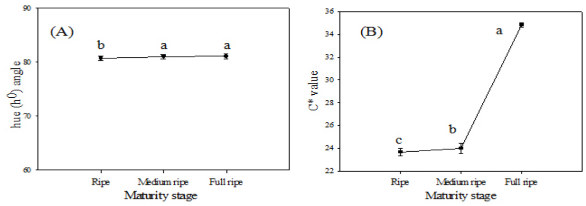

Figure 2. Hue (h°) angle (A) and Chroma (C* value) (B) of longkong at different stages of on-tree maturation

Note: Data are mean ± standard deviation (in fifteen replicates). Means with different superscript letters indicate that there are significant differences among maturity stages ($p < 0.05$).

to the brownish color that comes from enzymatic reaction. The enzymatic browning interacted with the substrate such as phenolic compounds and promoted fruit skin darkens (Sapii *et al*., 2000; Venkatachalam and Meenune, 2012). The results were in agreement with the study undertaken by Venkatachalam and Meenune (2012) who reported that a significant increase in a^* value was observed during maturation stages. More appropriate measures of fruit skin color can be obtained from the calculation of the Hue angle (h°) and the Chroma (C^*value). The fruit skin color of longkong at different stages of on-tree maturation in terms of h° and C^* value are shown in Figure 2. Increases in the angle of h° and C^* value at the mature stages of longkong were observed ($p < 0.05$). The angle of h° of the longkong at the ripe, medium ripe and full ripe stages was 80.74, 81.02 and 81.09. The angle of h° shown at nearly 90° indicates that the longkong skin becomes nearly yellow (h°, 90° = yellow). The results show a positive correlation with changes in CIE yellowness (b^*) which increased with the maturation of the fruit (Figure 1B). The chroma C^* value increased with the maturity of the longkong ($p < 0.05$). The C^* values of ripe, medium ripe and full ripe longkong were 23.65, 23.98 and 34.82, respectively. The highest C^* value was because of the high saturation from yellowness.

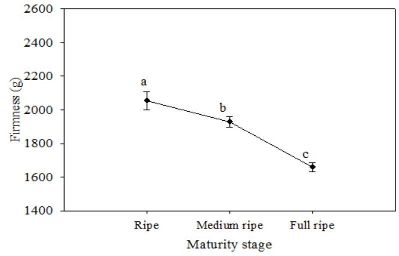

Figure 3. Firmness of longkong at different stages of on-tree maturation

Note: Data are mean ± standard deviation (in fifteen replicates). Means with different superscript letters indicate that there are significant differences among maturity stages ($p < 0.05$).

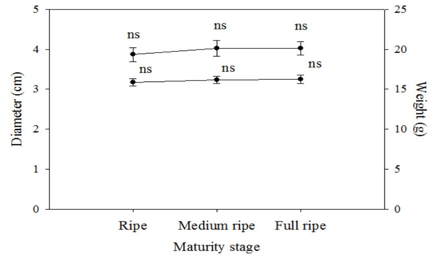

Figure 4. Diameter and weight of longkong at different stages of on-tree maturation

Note: Data are mean ± standard deviation (in fifteen replicates). ns = no significant differences among maturity stages ($p > 0.05$).

Fruit firmness

The loss of firmness in the fruit during fruit maturation is a major factor determining fruit quality. Changes in fruit firmness were associated with the stages of on-tree maturation. In ripe longkong, the fruit texture is firmer than that in the medium and full ripe stages. This can be indicated when using the highest force to penetrate into longkong at the ripe stage, which was 2,054.7 g. During the medium ripe to full ripe stages, fruit firmness decreased from 1,928.3 to 1,658.8 g (Figure 3). These phenomena could be explained by the degradation of the structural carbohydrates, cell wall disassembly and modifications to the pectin fraction by the role of pectin enzymes (White, 2002; Seymour and Gross, 1996).

Fruit size and weight

The size and weight of the longkong slightly increased from the ripe to full ripe stages ($p < 0.05$). The almost constant diameter of the longkong was observed in the ranges from 3.17 to 3.30 cm (ripe to full ripe stages) (Figure 4). This is in agreement with the standards of Tanyongmat the market in Narathiwat province. It prescribes that longkong grade A has a diameter of at least 3 cm or above. The fruit weight was found to be in the range from 19.94 g to 21.36 g (ripe to full ripe stages) (Figure 4). This is similar to the study of Bumrugrak (1992) which monitored the quality changes in longkong during its on-tree maturation (2 to 16 weeks after fruit set). It was found that at the ripe to full ripe stages (12 to 16 weeks after fruit set), the fruit weight and size remained almost constant. This is probably because a constant cell enlargement at these stages.

Chemical quality

Changes in chemical quality are important factors in determining the stage of fruit maturation. These are useful to determine the optimal harvesting time, such as the harvesting index. In this study, the chemical qualities (moisture content, pH, titrable acidity, total soluble solid and sugars) of longkong were evaluated during the edible stages of on-tree maturation (ripe, medium ripe and full ripe). The results were as follows.

Moisture content

The moisture content in the longkong varied significantly from the ripe to full-ripe stages during on-tree maturation ($p < 0.05$). The highest moisture content was observed at the full ripe stage. It was probably due to the movement of water from root throughout xylem into fruit cell during fruit maturation on-tree (Kays, 1991). In addition, an increase in the amount of the components such as sugars and acids in longkong during maturation might be affected on turgor pressure resulting in osmotic flow of water from area of low solute out into fruit cell (Campbell and Reece, 2008).

pH and TA

The pH increased significantly with on-tree maturation ($p < 0.05$). The pH values increased from 3.85 at the ripe stage to 4.27 at the full ripe stage (Table 1). The lowest acidity was found in longkong at the full ripe stage, which decreased significantly ($p < 0.05$) from 0.95% to 0.61%. This result was in agreement with the study undertaken by Sapii et al. (2000). They monitored the changes in the quality of longkong at different stages of ripeness (4, 7, 10 and 14 days after the fruit yellowed). It was found that the TA was significantly higher in the fruit harvested at the earlier stage. The acidity declined during ripening from 0.82% to 0.68%. The decreases of acidity during fruit maturation could be the main reason of pH increase, because acids were also used as a respiration substrate and produced the flavors (Wills *et al*., 1998).

TSS and sugars

There was a significant difference in the TSS, reducing and the total sugar contents in longkong at the different stages of on-tree maturation ($p < 0.05$). Table 1 shows that the TSS gradually

Table 1. Moisture content, pH, titrable acidity (TA), total soluble solid (TSS), reducing and total sugars in longkong at different stages of on-tree maturation

Maturity stage	Moisture content (%)	pH	TA (% as citric acid)	TSS (°Brix)	Reducing sugar (%)	Total sugar (%)
Ripe	$81.37±0.02^{c}$	$3.85±0.06^{c}$	$0.95±0.00^{a}$	$14.08±0.10^{c}$	$4.76±0.02^{c}$	$12.78±0.03^{c}$
Medium ripe	$81.64±0.10^{b}$	$4.00±0.01^{b}$	$0.77±0.00^{b}$	$16.65±0.06^{b}$	$5.05±0.01^{b}$	$15.13±0.01^{b}$
Full ripe	$82.03±0.14^{a}$	$4.27±0.01^{a}$	$0.61±0.00^{c}$	$17.50±0.08^{a}$	$5.38±0.04^{a}$	$15.59±0.01^{a}$

Note: Data are mean + standard deviation (in four replicates). Mean values in the same column with different superscript letters indicate that there are significant differences between the variety ($p < 0.05$).

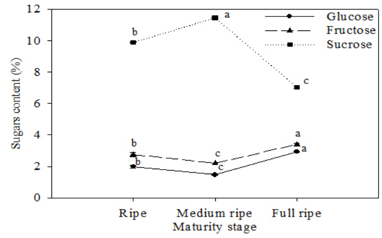

Figure 5. Types and concentrations of sugars content in longkong at different stages of on-tree maturation

Note: Data are mean ± standard deviation (in four replicates). Means with different superscript letters indicate that there are significant differences among maturity stages ($p < 0.05$).

increased significantly at the more mature stages of the ripening of the longkong ($p < 0.05$). The TSS increased significantly from 14.08 to 17.50°Brix. During maturation, reducing and the total sugar contents tended to increase ($p < 0.05$). The reducing sugar content increased from 4.76 to 5.38% during the ripe to full ripe stages. This finding indicated an increase in the total sugar content. The total sugar content increased from 12.78 to 15.59% during the ripe to full ripe stages (Table 1). The increase in the TSS could be attributed to the decomposition of the cell walls which caused the release of water-soluble components. In addition, increases in the TSS were probably due to the solubilization of neutral sugars from carbohydrate polymer residues (Beirao-da-Costa *et al.*, 2006). Increases in the TSS may be affected by the increase in the acids (Brady, 1987).

Types and concentrations of sugars

The main sugars were found in longkong were sucrose, fructose and glucose. The sucrose content increased slowly from 9.88 to 11.44%, during the ripe to medium ripe stages, and then gradually decreased to 7.03 at the full ripe stage ($p < 0.05$). The glucose content decreased from 1.98 to 1.46% from the ripe to medium ripe stages and increased to 2.92% in the full ripe stage. This was similar to the fructose content which decreased in the ripe to medium ripe stages, from 2.76 to 2.20%, and then increased to 3.39 at the full ripe stage (Figure 5). The decrease and increase in the glucose and fructose contents at the different stages of on-tree maturation could be explained by: the decrease was due to the rapid consumption of sugars in the respiration process to produce the energy required for the synthesis of the components. However, an increase in the glucose and

Table 2. Some organic acids in longkong at different stages of on-tree maturation

Maturity stage	Organic acid (%)		
	Citric acid	Maleic acid	Malic acid
Ripe	1.22±0.01[a]	0.40±0.01[a]	0.20±0.01[b]
Medium ripe	1.19±0.01[b]	0.36±0.01[b]	0.13±0.01[a]
Full ripe	0.79±0.01[c]	0.05±0.02[c]	ND

Note: ND = not detected
Data are mean ± standard deviation (in four replicates). Mean values in the same column with different superscript letters indicate that there are significant differences between the variety ($p < 0.05$).

fructose content at the full ripe stage may be due to the higher inversion reaction of the sucrose to glucose and fructose molecules (Ong *et al*., 2006).

Types and concentrations of organic acids

Citric, maleic and malic acids were monitored by HPLC in accord with Chairgulprasert *et al.* (2006). A reduction of the concentration of organic acids was observed during on-tree maturation ($p < 0.05$) (Table 2). The concentration of citric acid in the ripe stage was 1.22% and this was reduced from 1.19 to 0.79% in the medium ripe to full ripe stages. The maleic acid also decreased with on-tree maturation ($p < 0.05$). It was 0.40% in the ripe stage and then decreased to 0.36 and 0.05% in the medium ripe and full ripe stages, respectively. This was similar to the decrease of malic acid which decreased from 0.20 to 0.13% from the ripe to the medium ripe stages. However, the malic acid was not detected at the full ripe stage. This was probably due to the quick consumption of malic acid by it being conversed to pyruvate and being used as a substrate for the respiration process. In addition, the malic enzyme showed high activity in the late maturing fruit (Knee, 2002)

Volatiles flavor compounds

Fruit volatile flavor profile is directly influenced by fruit maturation. The formation of volatile flavor compounds in fruit is a dynamic process. Volatile flavor compounds are continuously synthesized and developed both qualitatively and quantitatively during fruit maturation. The volatile flavor compounds developed in longkong at the three different stages of on-tree maturation (ripe, medium ripe and full ripe) are shown in Table 3. The volatile flavor compounds included alcohols, terpenes, ketones and phenol. The terpenes and their derivatives were the major constituents. They promote the fruity, floral, flowery, herbaceous characteristics in longkong, which are normally found in a fruit aroma. In the ripe stage, the volatile flavor compounds which have fruity, floral, flowery, and herbaceous characteristics were not detected. Green aroma C6-alcohol (1-hexanol) was only the volatile flavor compound that was found in the ripe longkong. Thus it has a green aroma at the ripe stage. The longkong also showed some

Table 3. Volatile flavor compounds and their attributes identified in longkong at different stages of on-tree maturation

Compounds	Rt[A]	RI[B]	Attributes[C]	Peak area ($\times 10^4$) TIC[D]		
				Maturity stage		
				Ripe	Medium ripe	Full ripe
Alcohols						
1-hexadecanol	5.08	1116	floral, flower	nd	nd	1.64
n-butanol	6.19	1157	fruity	nd	nd	3.70
n-hexanol	11.05	1347	green	0.83	nd	nd
2-ethyl hexanol	14.89	1499	citrus, floral, sweet	1.89	5.61	nd
benzyl alcohol	23.77	1895	floral, sweet	nd	nd	1.53
Terpenes and their derivatives						
ortho-xylene	6.03	1150	geranium	nd	4.73	9.55
cis-linalool oxide	14.39	1479	floral, sweet	nd	nd	1.42
alpha-copaene	14.58	1486	woody	nd	nd	1.18
l-linalool	16.35	1559	fruity, sweet	nd	1.48	3.09
beta-caryophyllene	17.12	1591	fruity	nd	nd	4.08
d-germacrene	19.75	1706	herbaceous	4.56	15.68	26.54
bicyclogermacrene	20.29	1731	woody	nd	nd	2.01
delta-cadinene	20.84	1756	herbaceous	nd	1.49	2.97
para-cymene	32.56	2370	citrus	nd	4.47	nd
Ketones						
3-hydroxy-2-butanone	9.78	1298	sweet	14.83	16.48	26.75
Phenols						
phenol	26.38	2027	phenol	18.30	76.85	74.40

Note: [A] Rt = Retention time (min); [B] RI = Retention index (FFAP column) [C] References: http://www.thegoodscentscompany.com/rawmatex.html, http://www.flavornet.org/flavornet.html
[D] TIC = total ion current; [nd] = not detected

herbaceous and sweet characteristics by showing the lowest constituent levels of d-germacrene and 3-hydroxy-2-butanone. When the fruit became more mature, more terpenes and their derivatives were detected. As a consequence, more fruity and sweet characteristics were found.

Conclusion

During on-tree maturation, the physical, chemical and volatile flavor compounds in longkong are still changing. This information could indicate suitable harvesting times and the edibility of the fruit. The fruit skin became lighter and yellower with a softer flesh at the full ripe stage. Furthermore, the fruit size and weight was almost constant during the ripe to full ripe stages. The TSS and sugars increased while the acidity decreased with on-tree maturation, and this makes the fully ripe longkong more palatable. Organic acids such as citric, maleic and malic acids declined during on-tree maturation. The volatile flavor compounds were synthesized during on-tree maturation. The green aroma of 1-hexanol was the only tvolatile compound found in ripe longkong. The d-germacrene and 3-hydroxy-2-butanone were the major compounds in the medium and fully ripe longkong. These compounds were the components that gave the longkong more fruity and sweet characteristics.

Acknowledgment

The authors are grateful to the Prince of Songkla

University for the financial support.

References

A.O.A.C. 2000. Official Method of Analysis of Association of Official Analysis Chemist 17th. Virginia: The Association of Official Analytical Chemists, Inc.

Apai, W. 2010. Effects of fruit dipping in hydrochloric acid then rinsing in water on fruit decay and browning of longan fruit. Crop Protection 29: 1184-1189.

Beirao-da-Costa, S., Steiner, A., Correia, L., Empis, J. and Modlao-Martin, M. 2006. Effects of maturity stage and mild heat treatments on quality of minimally processed kiwifruit. Journal of Food Engineering 76: 616-625.

Brady, C.J. 1987. Fruit ripening. Annual Review of Plant Physiology 38: 155-178.

Bumrugrak, N. 1992. Study on the optimal harvesting time of longkong and the function of some chemicals for ripening. In: Proceeding the 30th Kasetsart University Seminar. Thailand, 29 January-1 February 1992. p. 129-136.

Campbell, N.A. and Reece, J.B. 2008. Biology (8th ed). Pearson Benjamin Cummings, UK.

Chairgulprasert, V., Krisornpornsan, B. and Hamad, A. 2006. Chemical constituents of the essential oil and organic acids from longkong (*Aglaia dookkoo* Griff.) fruits. Songklanakarin Journal of Science and Technology 28: 321-326.

Kader, A.A. 1999. Fruit maturity, ripening, and quality relationships. Acta Horticulturae 485: 203-208.

Kays, S.J. 1991. Postharvest Physiology of Perishable Plant Products. Van Nostrand Reinhold. New York.

Knee, M. 2002. Fruit Quality and Its Biological Basis. Academic Press. New York.

Lizana, C. 1993. Mango. In: Biochemistry of Fruit Ripening. (Seymour, G.B., Taylor, J.E., Tucker, G.A., eds.). p. 225-271. Chapman and Hall. London.

National Bureau of Agricultural Commodity and Food Standards. 2006. Longkong (Online). Available: *http://61.19.221.4/standard/standard/* download/ longkong.pdf [2007, December 01]

Ong, B.T., Nazimah, S.A.H., Osman, A., Quek, S.Y., Voon, Y.Y., Hashim, D.M., Chew, P.M. and Kong, Y.W. 2006. Chemical and flavour changes in jackfruit (*Artocarpus heterophyllus* Lam.) cultivar J3 during ripening. Postharvest Biology and Technology 40: 279-286.

Pantuvanid, N. 1985. Development, postharvest index and postharvest technology of Longkong (Online). Available: *http://www.phtnet.org/research/TypeResult.asp* [2006, August 18].

Paull, R.E. 2004. Longkong (Online). Available: *http://www.ba.ars.usda.gov/hb66/087/ longkong.pdf* [2007, December 01].

Rees, T.A.P., Dixon, W.L., Pollock, C.J. and Franks, F. 1981. Low temperature sweetening of higher plants. In: Recent Advances in the Biochemistry of Fruits and Vegetables. Friend, J. and Robert, M.J.C., eds.). p. 41-60. Academic Press, New York.

Sabah. 2004. Langsat, Duku, Duku-Langsat and Dokong (Online). Available: *http://www.sabah.gov.my/tani/english/crop_langsat.htm*[2007, December 01].

Sapii, A.T., Norlia, Y., Muda, P. and Lin, T.S. 2000. Postharvest quality Changes in dokong (*Lansium domesticum* Corr.) harvesed at different stages of ripeness. In: Proceeding the 19th ASEAN/1st APEC Seminar on Postharvest Technology. (Johnson, G.I., To, L.V., Duc, N.D. and Webb, M.C., eds.). Vietnam, 9-12 November 1999. p. 201-205.

Seymour, G.B. and Gross, K.C. 1996. Cell wall disassembly and fruit solftening. Postharvest News and Information 7: 45-52.

Soares, F.D., Pereira T., Marques, M.O.M. and Monteiro, A.R. 2007. Volatile and non-volatile chemical composition of the white guava fruit (*Psidium guajava*) at different stages of maturity. Food Chemistry 100: 15-21.

The office of agricultural economics. 2009. Agricaultural Statistics of Thailand 2009. Ministry of Agriculture and Cooperatives. Bangkok, Thailand.

Tucker, G.A. and Grierson, D. 1987. Fruit ripening. In: The Biochemistry of Plants. (Davies, D., ed.). p. 265-319. Academic Press Inc. New York.

Vendramini, A.L. and Trugo, L.C. 2000. Chemical composition of acerola fruit (*Malpighia punicifolia* L.) at three stages of maturity. Food Chemistry 71: 195-198.

Venkatachalam, K. and Meenune, M. 2012. Changes in physiochemical quality and browning related enzyme activity of longkong fruit during four different weeks of on-tree maturation. Food Chemistry 131: 1437-1442.

Wanakhachornkrai, P. and Lertsiri, S. 2003. Comparison of determination method for volatile compounds in Thai soy sauce. Food Chemistry 83: 619-629.

Wills, R.B.H., McGlasson, B., Graham, D. and Joyce, D. 1998. Postharvest: an Introduction to the Physiology and Handling of Fruits, Vegetables and Ornamentals. Hyde Park Press, Adelaide. South Australia.

White, P.J. 2002. Recent advances in fruit development and ripening: an overview. Journal of Experimental Botany 53: 1995-2000.