J. Trop. Agric. and Fd. Sc. 34(2)(2006): 257–268

Physico-chemical changes during ripening of ciku at different maturity stages

(Perubahan fiziko-kimia ciku semasa pemeraman pada tahap kematangan yang berlainan)

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Key words: ripening, maturity stages, fruit quality, ciku

Abstract

The maturity stage of ciku var. Subang at harvest influenced the flavour, taste and consumer acceptability of the fruit. Fruit harvested at 6.5–7 months after flower opening did not ripen properly and had poor flavour and taste. During ripening the chemical properties were poorly developed such that the fruit contained lower total soluble solids (12–15% Brix) and total sugars (7–10%). Fruit harvested at these stages (6.5–7 months after flower opening) were highly unacceptable. The best stage to harvest the fruit was at 7.5–8 months after flower opening. At this stage the fruit ripened properly within 4–6 days and the climacteric peak also occurred at the same time. The flesh colour changed to reddish brown and the total soluble solids and sugar contents increased to about 17–19% Brix and 12–15% respectively with pH 5–5.6. The proper development of total soluble solids, total sugars and acid contents gave the fruit good flavour and taste. Fruit harvested at these stages (7.5–8 months after flower opening) were highly acceptable.

Introduction

In the Third National Agriculture Policy (NAP3), ciku (*Achras sapota* L.) is one of the fruits that has been identified to be promoted for the development of the fruit industry in Malaysia (Anon. 1998). The cultivar Subang is one variety of ciku that has great potential for commercial cultivation. This cultivar is well received by consumers because of its sweetness and less gritty texture (Raziah et al. 1991). The fruit matures 7–9 months after flower opening (Siti Halijah and Tham 1996). However, it is difficult to determine the correct maturity stage for harvesting the fruit based on physical changes during maturation. Identification between an immature and mature fruit cannot be clearly differentiated by the size or colour of the fruit especially when the age is between 6.5–9 months after flower opening. At this age the size of the fruit is similar and there is not much change in the light brown colour of the skin. Other characteristics used for determining maturity indices such as reduction of the brown scales on the fruit surface and reduction in latex flow are also not very effective.

Harvesting at the correct maturity stage is important because it affects the flavour, aroma and storage quality, which

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collectively affects the commercial value of the fruit (Abdul Karim et al. 1987). Early harvest results in poor quality fruit that do not ripen properly while late harvest has poor storage quality. The ability of the fruit to ripen is greatly influenced by the stage of maturity. Therefore, the main objective of this study was to determine the correct stage of maturity for harvesting the fruit by observing the physical and chemical changes during ripening. The physiological behaviour of the fruit such as the rate of respiration and ethylene evolution will also be monitored. These changes greatly influenced the quality as well as consumer acceptance of the fruit.

Materials and methods

Ciku var. Subang was obtained from a farm in Kundang, Selangor. To obtain fruits at different maturity stages, tagging was done at flower opening. The fruits were tagged at random from several trees in the farm and allowed to develop and then harvested at 6.5, 7, 7.5, 8 and 8.5 months after flower opening. The harvested fruits were brought to the Food Technology Research Centre laboratory and sorted. Only good fruits were used in the experiment. They were then dipped in water and a soft cloth was used to remove the bloom and brown scales. At each harvest the fruits were divided into 2 lots; the first lot was used to determine the respiration rate and ethylene production of the fruit during ripening, while the second lot was used for studying the changes in the physico-chemical characteristics during ripening. For data verification, the experiment was repeated twice.

Respiration rate and ethylene evolution

To determine the respiration rate and evolution of ethylene during ripening, 16 fruits were taken at each harvest. Half of the fruits was induced with 5 ppm ethylene at 20 °C for 24 h while the other half was not induced. All fruits were put into respiration chambers, which have inlet and outlet tubes, and allowed to ripen at the same temperature. Two fruits, which formed one replicate, were placed in each chamber and each maturity stage had four replicates. Each chamber was continuously passed with humidified air through the inlet tube at a flow rate of approximately one litre/100 g of fruit per hour. Respiration rate and ethylene evolution were measured daily until the fruit ripens.

Respiration rate was measured by the rate of CO_2 given off by the fruit. The gas was measured by extracting one millilitre of the respired air from the outlet tube and injecting it into a Varian 1420 thermal conductivity detector gas chromatograph fitted with stainless steel column packed with Porapak R of size 80–100 mesh. The carrier gas was helium at a flow rate of 30 ml/min with 30 °C column temperature. The respiration rate was calculated from the CO_2 concentration measured and the gas flow rate through the respiration chamber containing the fruit.

The amount of ethylene was measured using the Varian 1440 flame ionization detector gas chromatograph fitted with Porapak T column of 100–120 mesh size. The carrier gas was nitrogen at a flow rate of 30 ml/min and oven temperature of 100 °C.

Physico-chemical changes during ripening

To determine the physico-chemical changes during ripening, the fruits were induced with 5 ppm ethylene to facilitate even ripening. Sampling and observation was carried out before the fruits were induced, 24 h after ethylene induction and after the fruits ripened at 6 days after induction. To determine these changes, 30 fruits were taken at each harvest; 10 fruits were not induced for determination of quality before induction. The remaining 20 fruits were induced with 5 ppm ethylene at 20 °C for 24 h. From the induced fruits, 10 were analysed 24 h after induction while the remaining fruits were allowed to ripen at 20 °C for 6 days. Each observation was done in five replicates (two fruits/replicate)

and the experiment was repeated twice in the same season.

Analyses were carried out for changes in flesh colour, texture, moisture content, total soluble solids (TSS), total sugars (TS) and pH.

Changes in flesh colour were measured using the Minolta CR200 chromameter which expressed colour in three numerical notation system as L*, a* and b* values. L* denotes the lightness and darkness of the colour while a* and b* denote the hues which represent two colour axes with a* the red-green axis and b* the yellow-blue. The chroma (C*), which indicates the intensity of the colour, was also calculated using the formula:

$$C^* = \sqrt{(a^{*2} + b^{*2})}.$$

The texture of the fruit was determined by the puncture test using the Instron 1140 machine. A puncture was made on the equatorial region of each fruit with a 11-mm Magness Taylor probe using load cells of 200 kgf and 50 kgf for unripe and ripe fruits respectively. The machine was operated with cross-head and chart speeds of 50 and 100 mm/min respectively. The force (kg/mm^2) that was required to puncture the fruit was calculated by dividing the peak height with the area of the probe head.

Determination of the percentage moisture content of the fruit was done using the air-oven method (AOAC 1984). Each fruit was homogenised in a blender and 10–15 g of the blended sample was taken and dried in the oven overnight at 105 °C until a constant weight was obtained. The percentage of moisture content was calculated based on the amount of weight loss by the sample. Two samples were taken from each fruit.

The pH was measured by blending the fruit at room temperature and readings were taken using the Orion digital pH meter model SA520. The TSS of the fruit juice was measured using an Atago digital refractometer (0–32% Brix). Total sugars were analysed by the method of Lane and Eynon (AOAC 1975).

To have an indication of the overall acceptability of the fruit for consumption after ripening, 10 fruits were taken at each harvest and induced to ripen with 5 ppm ethylene. After ripening the skin was removed and the fruits were tasted and scores were given for sweetness, flavour and acceptability. The scores for sweetness were 1 = not sweet (flat), 3 = slightly sweet, 5 = sweet and 7 = very sweet; and flavour 1 = very poor, 3 = slightly poor, 5 = good and 7 = very good. The scores for acceptability were 1 = not acceptable, 3 = slightly acceptable, 5 = acceptable and 7 = highly acceptable.

A completely randomized design was used for the experimental set-up, with three treatments (ripening stages – before induction, 24 h after induction, and at ripening 6 days after induction) and five replicates. Readings of the treatments were taken at five points of harvest maturity (6.5, 7, 7.5, 8 and 8.5 months after flower opening). Each harvest maturity point gave a single-factor analysis of variance comparing the different ripening stages. Assuming homogeneity of the variances, a single-factor analysis of variance was also carried out to compare the five points of harvest maturity at each ripening stage.

Results and discussion

Respiration rate and ethylene evolution

In general the pattern of respiration and ethylene evolution of ciku var. Subang follows that of climacteric fruit. But, respiration rate and ethylene production during ripening differed at different maturity stages. Fruit harvested at 6.5 months after flower opening had very low respiration rate and ethylene production *(Figure 1)*. No respiratory climacteric or an upsurge in ethylene production was observed. This was because the fruit was still in the process of maturation and development of the fruit was still in the preclimacteric growth stage. At this stage the fruit was still able to enlarge (Siti Halijah and Tham 1996). Since there was no pronounced increase in respiration,

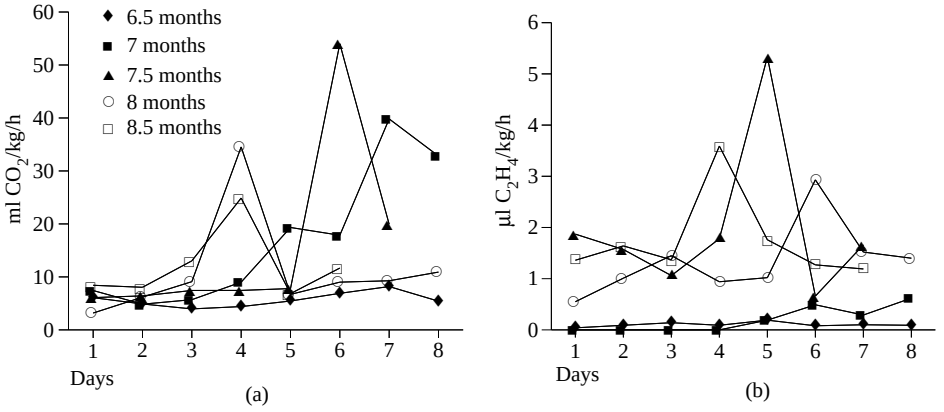

Figure 1. Respiration rate (a) and ethylene production (b) of ciku var. Subang during natural ripening at different maturity stages for 8 days at 20 °C

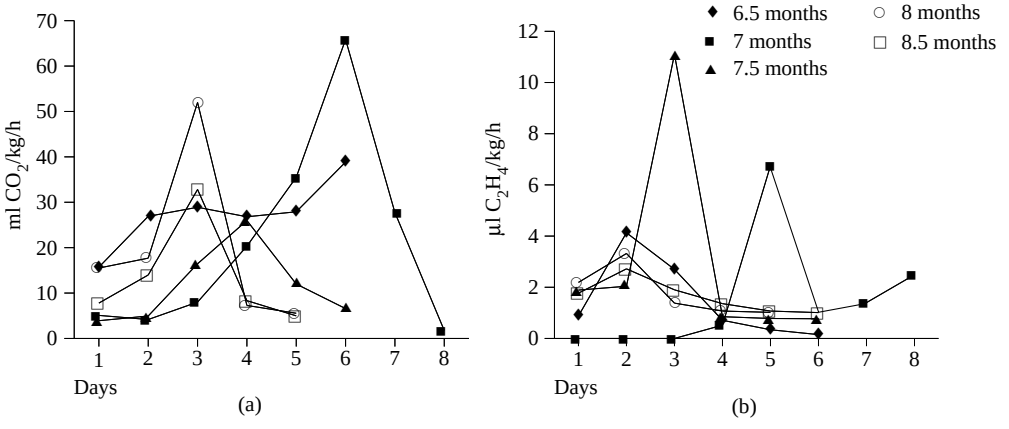

Figure 2. Respiration rate (a) and ethylene production (b) of ciku var. Subang after induction with 5 ppm exogenous ethylene at different maturity stages for 8 days at 20 °C

which normally coincides with ripening of climacteric fruit (Wills et al. 1989), ciku fruits harvested at this stage undergo senescence without proper ripening.

Respiratory climacteric and upsurge in ethylene production were only observed during natural ripening when the fruits were harvested between 7 and 8.5 months after flower opening. At 7 months the preclimacteric stage was longer than the other harvesting stages. The respiratory climacteric peak occurred 7 days after harvesting *(Figure 1a)* with no distinct upsurge in ethylene production *(Figure 1b)*. As the fruit matured, the preclimacteric stage became shorter and the respiratory climacteric occurred earlier. Fruit harvested at 7.5 months reached climacteric peak 6 days after harvesting while those harvested at 8 to 8.5 months peaked at 4 days after harvesting *(Figure 1a)*. The upsurge in ethylene production also peaked at about the same time i.e. within 4–6 days *(Figure 1b)*.

The fruit responded positively when induced to ripen with 5 ppm exogenous ethylene. There was a 5-fold increase in the respiration rate of fruit harvested at 6.5 months *(Figure 2a)* but no distinct climacteric peak was observed. At this stage the respiration rate averaged at 5 ml CO_2/kg/h when the fruit was allowed to ripen naturally *(Figure 1a)*; but after induction with ethylene, the rate increased to an average of 25 ml CO_2/kg/h *(Figure 2a)*.

Treating the younger fruit with ethylene also seemed to promote the synthesis of ethylene forming enzyme (Abeles et al. 1992). This was indicated by the increase in the evolution of ethylene in fruit harvested at 6.5 and 7 months, and an ethylene peak was also observed within two days and five days after induction respectively *(Figure 2b).* At the other harvesting stages the treatment hasten the climacteric peak as well as the upsurge in ethylene production at least a day earlier than fruit that were not induced with ethylene. This phenomenon was also reported by Latifah (1996). Fruits harvested at 7 months after flowering reached climacteric peak 6 days after harvesting, 4 days for fruits harvested at 7.5 months and 3 days for those harvested at 8–8.5 months *(Figure 2a).* It was also observed that the ethylene concentration rose earlier before the onset of ripening.

Physico-chemical changes during ripening

As the fruit matured, significant changes occurred in the physical and chemical attributes which affect the fruit quality (Abdul Karim et al. 1987; Siti Halijah and Tham 1996). These include changes in colour, size, weight, texture, total soluble solids, total sugars, pH and total titratable acidity.

The first significant change was found in the colour of the flesh. During maturation there was a significant decrease in the L* values followed by a significant increase in a*, b* and C* values especially before the fruit ripens *(Figure 3)*. The decrease in the L* values indicated that the colour of the flesh became darker as the maturity increased. The increase in the a* and b* values indicated that the colour changed towards the red and yellow hues and the intensity of the colour (C* values) increased

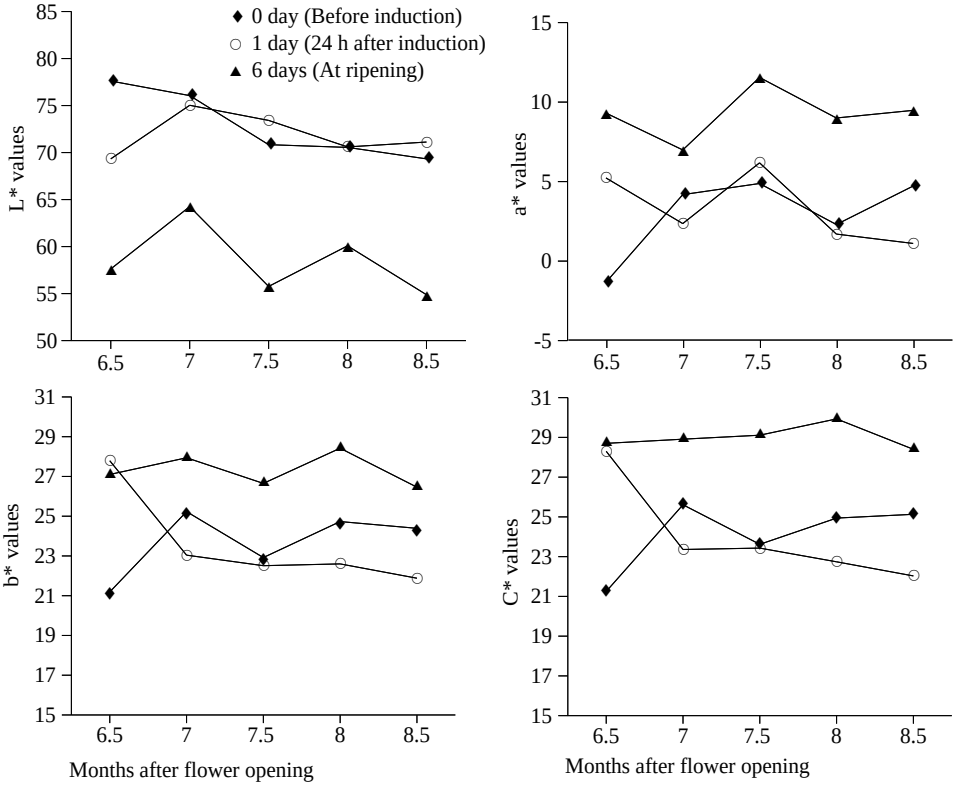

Figure 3. Changes in flesh colour (L, a*, b*, C* values) of ciku var. Subang at different maturity stages*

during maturation. These changes were observed before the fruits were induced with 5 ppm ethylene *(Figure 3).*

During ripening similar changes were also observed which occurred at all stages of maturity *(Figure 4)*. Ripening changed the colour of the flesh from the original light brown colour to a darker reddish-yellowish brown. Again, this was indicated by the reduction in the L* values followed by the increased in a*, b* and C* values *(Figure 4)*. This can be clearly seen as the values changed from day 0 to day 6 after induction. However, after ripening there were no significant differences in the colour of the flesh at the various maturity stages *(Figure 3)*.

The texture and moisture content of the fruit also changed during maturation and ripening. During maturation significant reduction in the force required to puncture the fruit began when the fruits were about 7–7.5 months after flower opening *(Figure 5)*. However, when the fruits were induced with 5 ppm ethylene, the flesh quickly softened within 24 h after induction at all stages of maturity *(Figure 6)*. Softening occurred because of the breakdown of polymeric carbohydrates especially pectic substances and hemicelluloses that weakened the cell walls and the cohesive forces binding the cells together (Wills et al. 1989).

It was observed that the rate of softening of ciku var. Subang differed at different maturity stages *(Figure 6)*. This was probably due to the different rate of degradation of the pectic substances, which was directly correlated with the rate of the fruit softening (Wills et al. 1989). Fruits harvested at all stages of maturity undergo rapid softening during ripening as indicated by the lower force required to puncture the fruit *(Figure 6)*. The ripened fruits were

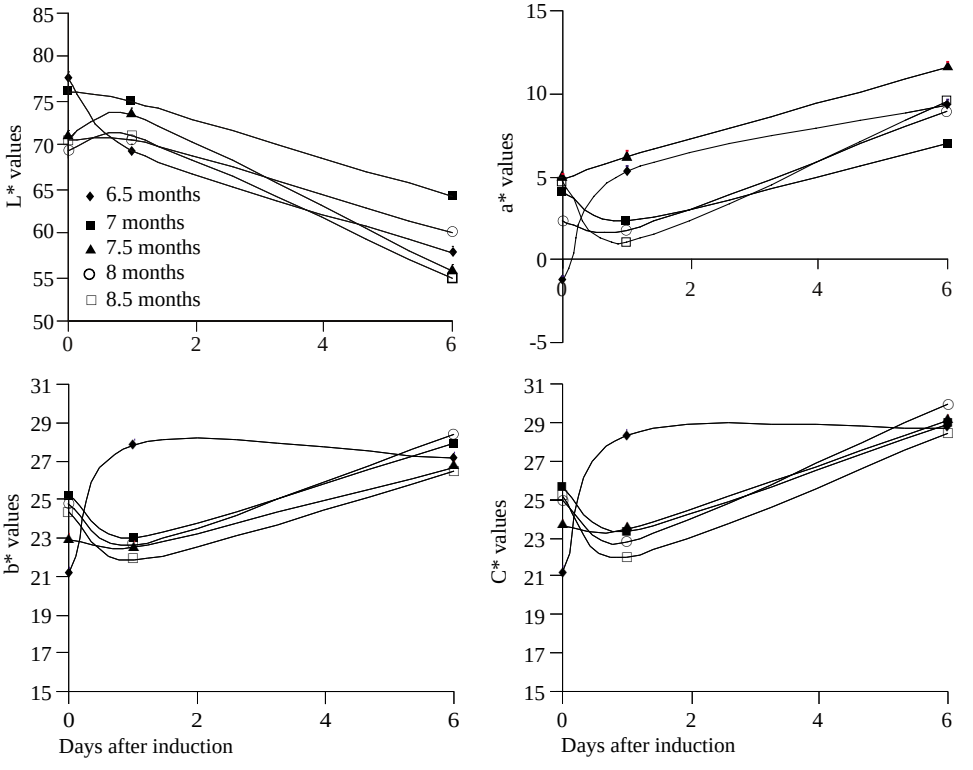

Figure 4. Rate of change in flesh colour (L, a*, b*, C* values) of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages*

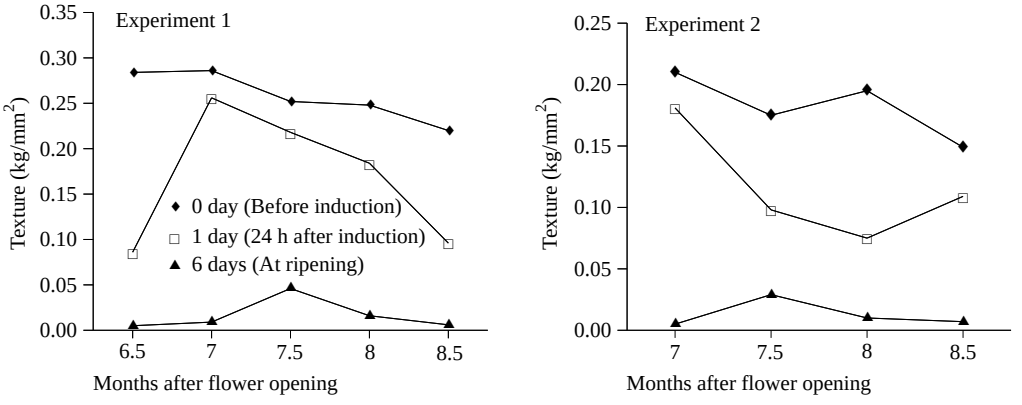

Figure 5. Changes in texture (kg/mm²) of ciku var. Subang at different maturity stages

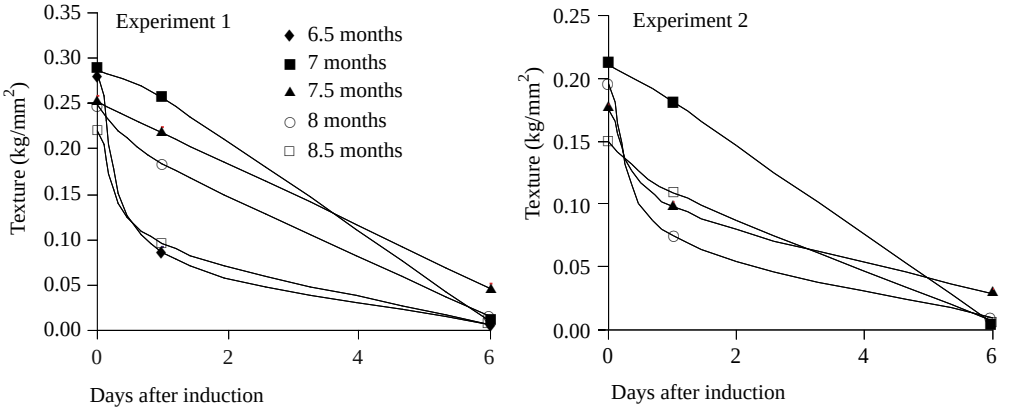

Figure 6. Rate of change in texture (kg/mm²) of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages

firmer when harvested at 7.5 months after flower opening *(Figure 5)*. At this stage a force of 0.03–0.05 kg/mm² was required to puncture the fruit while the other stages required less than 0.02 kg/mm².

The fruit also significantly lost moisture during maturation and the lost in moisture gradually began at 7 months after flower opening *(Figure 7)*. The decreasing trend in the moisture content may indicate the complete maturity of the fruit, because it had been shown that ciku gained moisture during fruit development and gradually lost moisture when complete maturation was attained (Abdul Karim et al. 1987; Siti Halijah and Tham 1996). About 3–4% moisture was lost when the fruit was harvested at complete maturation stage (8–8.5 months after flower opening). Moisture loss also occurred during fruit ripening at all stages of maturity *(Figure 8)*. About 1% of the moisture was lost when the fruit ripen at these stages. Moisture loss during ripening was probably due to respiration and transpiration.

Changes in the chemical attributes greatly affect the flavour and taste of the fruit and thus influenced its eating quality and acceptability. Taste scores indicated that ciku fruits harvested at 7.5 to 8.5 months after flower opening were acceptable for consumption *(Figure 9)*. At these stages of maturity the fruits were able to ripen with good flavour and taste as indicated by the sweetness scores of 4.5–5.4, flavour scores of 4.8–5.2 and acceptability scores of

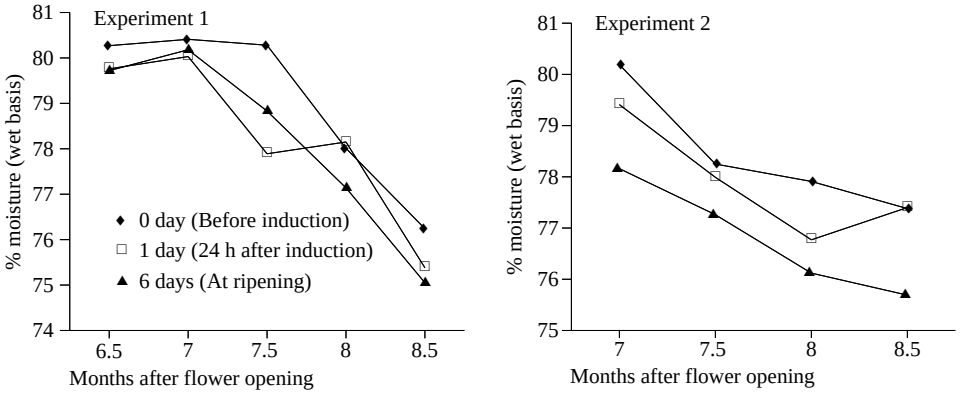

Figure 7. Changes in moisture content (%) of ciku var. Subang at different maturity stages

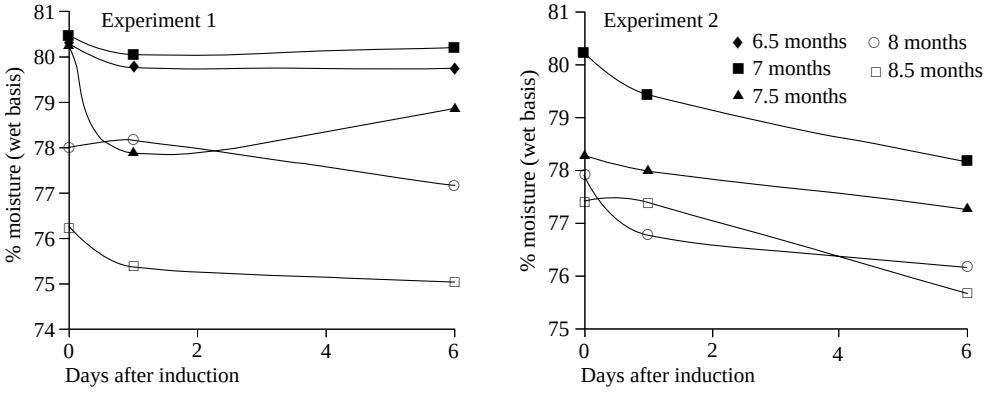

Figure 8. Rate of change in moisture content (%) of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages

4.5–5.7 *(Figure 9)*. Fruit harvested at 6.5–7.0 months after flower opening did not ripen properly and was found to be unacceptable for consumption *(Figure 9).*

Development of good flavour and taste was attributed to the changes in the total soluble solids, total sugars and pH. During maturation there was a significant increase in the total soluble solids *(Figure 10)* but during ripening all samples showed significant reduction in the percentage of total soluble solids *(Figure 11).* The greatest amount of reduction, however, occurred in younger fruits i.e. fruit harvested between 6.5–7 months after flower opening. At these stages there was an average loss of about 3–7% Brix total soluble solids. At 6.5–7 months the unripe fruit contained about 17–18% Brix total soluble solids but after

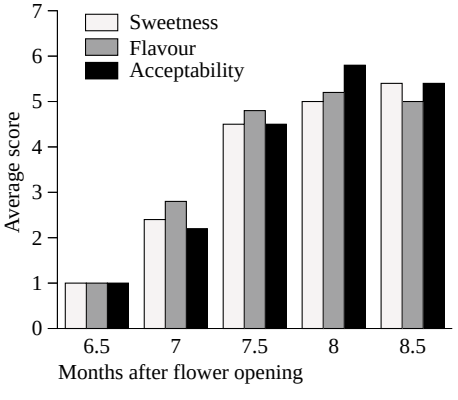

Figure 9. Average scores for sweetness, flavour and acceptability of ciku var. Subang ripened at different maturity stages

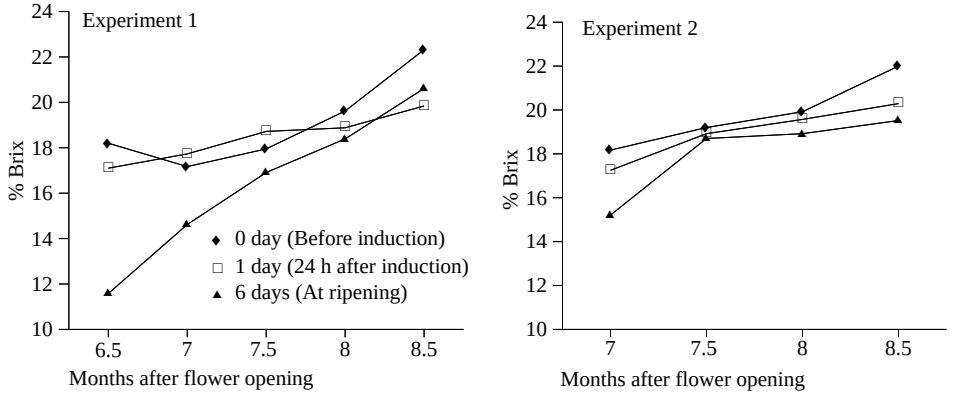

Figure 10. Changes in total soluble solids (% Brix) of ciku var. Subang at different maturity stages

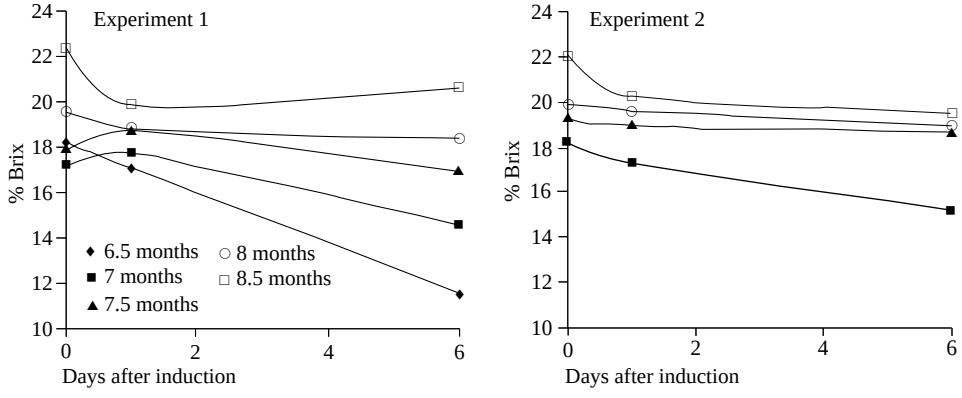

Figure 11. Rate of change in total soluble solids (% Brix) of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages

ripening (6 days after induction) the total soluble solids were reduced to about 12–15% Brix *(Figure 11)*. This affects the flavour and taste of the fruit, which renders it to be unacceptable *(Figure 9)*. Fruit harvested at 7.5, 8 and 8.5 months only lost about 1% of their total soluble solids and after ripening still contained about 17–21% Brix.

The reduction in the total soluble solids is probably due to it being used as a respiratory substrate during the metabolic process. The initial pathway is that of glycolysis where sugar, especially glucose is broken into pyruvic acid which then enters the Krebs cycle and oxidized to carbon dioxide in the mitochondria (Kays 1991). In younger fruits (6.5–7 months after flowering) a higher percentage of the total soluble solids seem to be used as a substrate in the respiratory process. This can be related to the 5-fold increase in the respiration rate of the ripening fruits *(Figure 2a)*.

Significant changes occurred in the percentage of total sugars during maturation *(Figure 12)* as well as during ripening *(Figure 13)*. Higher concentration of total sugars was obtained when fruits were harvested between 7.5–8.5 months after flower opening *(Figure 12)*. At these stages, the fruit contained between 12–15% total sugars after ripening. Fruits harvested at 6.5–7.0 months showed only a slight change in total sugars *(Figure 13)* and after ripening less than 10% was found in the fruit tissues and this amount was insufficient to give good flavour and taste. All of the fruits

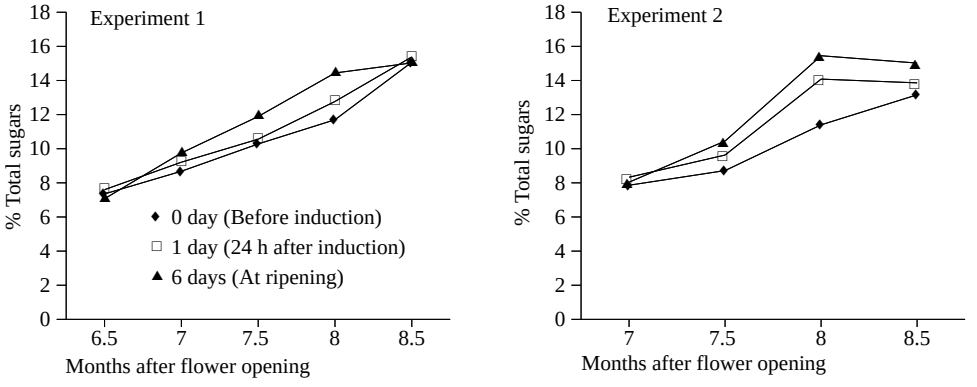

Figure 12. Changes in total sugars (%) of ciku var. Subang at different maturity stages

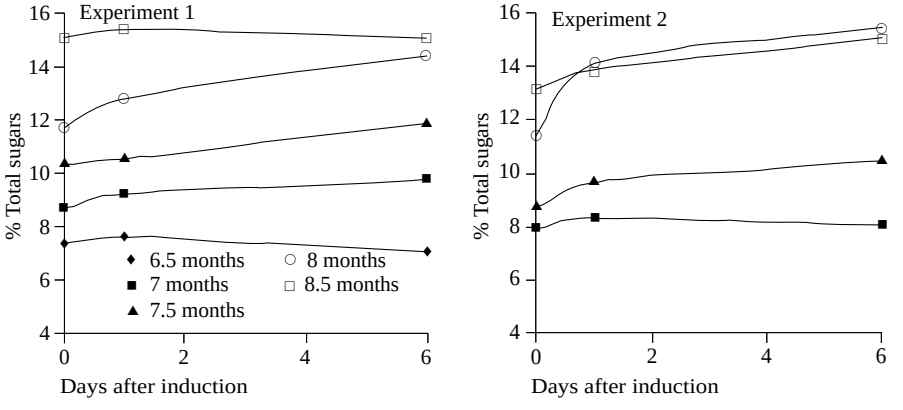

Figure 13. Rate of change in total sugars (%) of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages

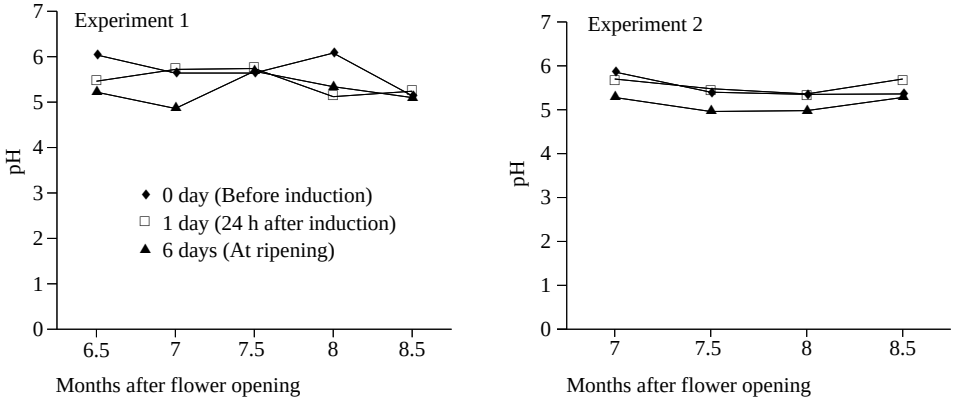

Figure 14. Changes in pH of ciku var. Subang at different maturity stages

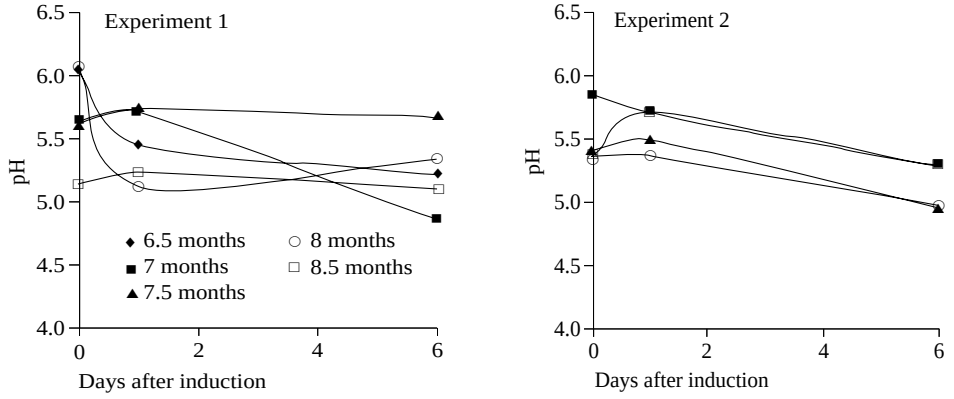

Figure 15. Rate of change in pH of ciku var. Subang during ripening (after induction with 5 ppm ethylene) at different maturity stages

harvested at these stages were totally unacceptable because of poor flavour and taste *(Figure 9)*. The fruits were acceptable *(Figure 9)* when the total sugar content ranged between 12–15% which was found in fruits harvested at 7.5–8.5 months after flower opening *(Figure 12)*.

Changes in pH also affect the flavour and taste of the fruits. There was a gradual decrease in pH during maturation *(Figure 14)*. However, after ripening the pH remained between 5–5.6 at all harvest maturity *(Figure 15)*.

Conclusion

The harvest maturity of ciku var. Subang can be determined based on the age and physico-chemical changes of the fruit. At 6.5–7 months after flower opening the fruit is still immature and not suitable for harvesting. At this stage the fruit have poor taste and flavour due to reduction of total soluble solids during ripening and poor development of total sugars. The best harvesting stage is between 7.5–8 months after flower opening. Fruit harvested at this stage were firmer and exhibited good flesh colour development during ripening. The flavour and taste of the fruit were also acceptable because of proper development in total soluble solids, total sugars and acidity during ripening. There was a high percentage of total soluble solids (17–19% Brix) and total sugars (12–15%) present in the fruit tissues after ripening. This gave the fruit an acceptable flavour and taste, which was balanced by the presence of fruit acids which renders a pH between 5–5.6. At 8.5 months after flower opening the fruit was already over matured. The fruit softened rapidly and thus have a shorter storage life.

Acknowledgement

The authors would like to thank Mr John Ng, Mr Abdul Rahman Moidu and Mr Ismail Mustam for assisting in the data collection. The assistance of Mr Yunus Jaafar was also greatly appreciated in the statistical analysis of the data.

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Abstrak

Peringkat kematangan bagi ciku var. Subang semasa dituai mempengaruhi cita rasa dan penerimaan pengguna terhadap buah tersebut. Buah ciku yang dipetik 6.5–7 bulan selepas bunga mengembang tidak masak dengan sempurna dan mempunyai cita rasa yang tidak enak. Semasa pemeraman sifat-sifat kimia tidak berkembang dengan sempurna menyebabkan buah ciku mengandungi jumlah pepejal larut (12–15% Brix) dan jumlah gula (7–10%) yang rendah apabila masak. Buah ciku yang dipetik pada tahap ini (6.5–7 bulan selepas bunga mengembang) tidak diterima dengan baik. Tahap yang paling baik memetik buah ciku ialah 7.5–8 bulan selepas bunga kembang. Pada tahap ini buah ciku akan masak dengan sempurna dalam masa 4–6 hari dan puncak klimaktrik berlaku pada masa yang sama. Warna isi bertukar perang kemerahan dan kandungan pepejal larut dan gula masing-masing meningkat pada tahap 17–19% Brix dan 12–15% dengan pH 5–5.6. Kandungan pepejal larut, gula dan asid ini dapat memberi keseimbangan pada cita rasa buah. Buah yang dipetik pada tahap ini (7.5–8 bulan selepas bunga kembang) dapat diterima dengan baik.

Accepted for publication on 4 October 2005