Research Article

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Determination of optimum harvest maturity and physico-chemical quality of Rastali banana (*Musa* AAB Rastali) during fruit ripening

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Abstract

BACKGROUND: A series of physico-chemical quality (peel and pulp colours, pulp firmness, fruit pH, sugars and acids content, respiration rate and ethylene production) were conducted to study the optimum harvest periods (either week 11 or week 12 after emergence of the first hand) of Rastali banana (*Musa* AAB Rastali) based on the fruit quality during ripening.

RESULT: Rastali banana fruit exhibited a climacteric rise with the peaks of both CO_2 and ethylene production occurring simultaneously at day 3 after ripening was initiated and declined at day 5 when fruits entered the senescence stage. De-greening was observed in both of the harvesting weeks with peel turned from green to yellow, tissue softening, and fruits became more acidic and sweeter as ripening progressed. Sucrose, fructose and glucose were the main sugars found while malic, citric and succinic acids were the main organic acids found in the fruit.

CONCLUSION: Rastali banana harvested at weeks 11 and 12 can be considered as commercial harvest period when the fruits have developed good organoleptic and quality attributes during ripening. However, Rastali banana fruit at more mature stage of harvest maturity taste slightly sweeter and softer with higher ethylene production which also means the fruits may undergo senescence faster than fruit harvested at week 11.

Keywords: physiological maturity; respiration; ethylene; ripening; physico-chemical quality

INTRODUCTION

Banana is a non-seasonal fruit that can be produced throughout the year in large quantities. For economic importance, *Musa* contributed to world production with 102 million metric tonnes, of which about 68% was classified as bananas and 32% as plantains.[1] In Malaysia, the production yield of banana increased from 272 331 metric tonnes in 2008 to 306 356 metric tonnes in 2011.[2] Rastali banana (*Musa* AAB Rastali) is one of the favourite dessert bananas that have a good potential for export in Malaysia and the cultivation area has increased by 40% from 2000 to 2007.[2] Furthermore, Rastali banana is also cultivated and commands a high price in all parts of India.[3] Rastali banana belongs to the Musaceae family and has a slightly astringent taste as compared to other varieties of banana. This astringent taste is the trademark of Rastali banana.[4] Therefore, potentially, Rastali banana has a bright future as a premium dessert variety, such as the Cavendish banana in the local and world market.

Fruit ripening is the final stage of fruit development which involves series of physiological and biochemical changes resulting in more attractive and a better taste of fruits. Normally, obvious and significant physical changes of a ripening fruit are the changes of fruit skin colour and fruit firmness.[5] Chemical changes in fruits, such as organic acids and sugars contents, are associated with respiration and ethylene production, with a sudden rise during the climacteric stage of fruit ripening; for example, apples,[6] mango[7] and litchi[8] generate greater aroma during ripening.

Bananas (*Musa* sp.) are categorised as climacteric fruits where the fruits will exhibit a short shelf life because of rapid deterioration of the peel colour and pulp firmness once ripening is initiated with ethylene.[9] Thus, bananas need to be harvested at the optimum stage of maturity during fruit growth and development in order to assure the best final quality of the fruit and for sufficient shelf life for marketing.[5] Different harvest times may result in variability of fruit quality after harvest during ripening of Cavendish banana.[10] The same authors reported that firmer banana fruit harvested at an earlier stage of maturity exhibit a delayed ethylene peak as compared to softer banana fruit harvested at a later stage of maturity. Furthermore, fruits harvested at a later stage of maturity were sweeter, less sour and generally had more intense aroma characteristics.[11]

Previous research carried out in Rastali banana reported that it was ready for harvesting when fruit reached maturity at week 11 (77 days) and week 12 (84 days) after the emergence of the

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first hand.[12] However, the research did not suggest an optimum harvest period (either week 11 or week 12 after emergence of the first hand) in order to gain better eating quality during ripening. Furthermore, fruits from different hand positions (top, middle and bottom) within the same bunch of bananas have different stages of maturity and ripening.[13] Thus, this present research was carried out to determine the physico-chemical quality of Rastali banana harvested at two different maturity periods (either week 11 or week 12 after emergence of the first hand) and hand positions during ripening in order to determine the optimum harvest period of Rastali banana for commercial purposes.

MATERIALS AND METHODS

Plant material

Fruit bunches of Rastali bananas were obtained from the experimental field of Universiti Putra Malaysia. The experiment was carried out between March and July 2009. Forty-eight trees were tagged and fruits were bagged with a blue plastic bag once the first hand (basal fruit at the top) emerged and was considered as day 1 (D1). The tagged fruit bunches were allowed to calculate of the number of weeks of fruit development and harvested when the fruit reached maturity at week 11 (D77) and week 12 (D84). (31 May, 29 June and 1 July 2009) based on the emergence of the first hand (12 March, 8 April and 15 April for week 11; 9 March, 7 April and 9 April 2009 for week 12, respectively). The harvesting was done in the morning and the fruit was transported to the Postharvest Laboratory. The ripening process and analysis were carried out immediately after the fruit had arrived. Six hands within a bunch of Rastali banana were used in this study and hands were numbered from the top to the bottom (hand 1: basal fruit at the top; hand 6: distal hand at the bottom). Three fingers from either the upper or lower whorls of each hand were selected randomly as sub-samples for each ripening days (six hands $\times$ three fingers $\times$ four ripening days $=$ 72 fingers per tree). Thereafter, 432 finger samples were collected at a total of two harvesting stages for three replications (72 fingers $\times$ two harvesting stages $\times$ three replications $=$ 432 samples).

Ripening process

Mature green fruit of Rastali banana was washed, dried and hands were dehanded from the pseudo-stem. Six hands within the same bunch of Rastali banana were placed in a sealed airtight box. Then, 100 mL L^{-1} of ethylene gas was then injected into the box under $25 \pm 2\,^{\circ}C$ and 65% of relative humidity and allowed ripening initiation for 24 h.[14] After ripening initiation, banana fruits were removed from the box and allowed to ripen for 5 days under the same condition as ripening initiation. Postharvest quality tests, including physical, chemical and physiological tests, were carried out on days 0, 1, 3 and 5 after ripening initiation.

Determination of peel and pulp colours

The peel and pulp colours were determined using a chroma meter (CR-300; Minolta Corp., Osaka, Japan). The colour determination was peformed at the top, middle and bottom region from three different faces of an individual finger. The readings were expressed in chromaticity values of lightness (L^*), chroma (C^*) and hue (h°). The L^* coordinate ranged from zero (dark) to 100 (white), and C^* values measured the vividness of the colours. The h° value was the angle in a colour wheel of 360° used to classify the colours, and the h° value groups were 0°, 90°, 180° and 270° corresponding to the red, yellow, green and blue hues, respectively.

Determination of pulp firmness

Pulp firmness was determined using a penetrometer (Bishop Penetrometer FT 327, Alfonsine, Italy). The force required for a 8 mm diameter cylindrical probe to penetrate a 1 cm transversely cut surface of the fruit pulp to a depth of 0.8 cm was recorded. Constant force was applied with three punctures test was made on stem end, middle and floral end of the fruit. The penetrometer readings in kilogram-force were then converted to newtons (N) as follows: firmness (N) $=$ force (kg)/probe area (cm^2) $\times$ 10.

Determination of pH

Five grams of pulp obtained from a fruit finger was homogenised with 40 mL of distilled water. The pH was determined by using a pH meter (GLP 21, Crison, Barcelona) with calibration of buffer at pH 4.01 followed by pH 7.0.

Determination of sugars content

Soluble sugars were extracted by grinding 10 g of flesh tissue from one finger of each hand in 40 mL of distilled water at 18 °C, before centrifuging the mixture at 3000 $\times$ *g* for 20 min. The sample was filtered twice, first through a Sep-Pack C-18 cartridge, with a 0.45 µm pore filter and 100 µL of sample was injected into the high-performance liquid chromatography (HPLC) system (Jasco LG-1580-04; Jasco, Tokyo, Japan) using 80% of acetonitrile (flow rate 1.0 mL min^{-1}) as solvent. The system consisted of a refractive index detector (RI-1530; Jasco) equipped with a Sugar Pak column (250 mm $\times$ 4.6 mm) (APS-2 Hypersil, Milford, USA). Fructose, glucose and sucrose were identified and quantified by comparison with the retention time and integrated peak areas of sugar standard and were expressed in grams per litre.

Determination of organic acids content

Five grams of pulp were chopped and homogenised with 20 mL of 0.005 mol L^{-1} sulfuric acid. The homogenate was diluted to 50 mL of 0.005 mol L^{-1} sulfuric acid and then was filtered before being centrifuged at 2250 $\times$ *g* for 5 min. A 200 µL aliquot of the filtered sample was eluted with 1800 µL of 0.005 mol L^{-1} sulfuric acid and was analysed using a Jasco HPLC with a UV–visible detector (210 nm wavelength) equipped with an Aminex HPX-87H column (BioRad, Hercules, California, USA). A 100 µL aliquot was injected into the HPLC system (Shimadzu, Kyoto, Japan) using 4 µmol L^{-1} sulfuric acid (flow rate 0.60 mL min^{-1}) as solvent. Malic acid, succinic acid and citric acid were identified by comparison with the retention times and integrated peak areas of organic acid standard and were expressed in grams per litre.

Determination of respiration rate and ethylene production

Fruit respiration and ethylene (C_2H_4) production were determined according to the static method[15] by using gas chromatography (Clarus 500; Perkin Elmer, Shelton, CT, USA) with a flow rate of 25 mL min^{-1}. The system was equipped with a flame ionisation detector (150 °C) and thermal conductivity detector (150 °C) with a stainless steel Porapak Q Column (3 m $\times$ 3.125 mm; 50/80 mesh) (Supelco, Sigma-Aldrich, St Louis, MO, USA) where hydrogen (flow rate 45 mL min^{-1}) was used as the carrier gas. One finger from each hand was incubated individually in a stackable airtight container (1.9 L) at room temperature ($25 \pm 2\,^{\circ}C$) for 2 h. An aliquot (1 mL) of the exit flow from the container was injected into the injector port on the gas chromatograph for determination of CO_2 and C_2H_4 concentrations, respectively,

using a syringe. Different fruit fingers were detached from each hand in order to measure the CO_2 and C_2H_4 concentrations on each ripening day. Instruments were calibrated using certified standards.

Statistical analysis

The experimental design was a randomised complete block design (RCBD). The treatments were a 6 × 2 × 4 factorial arrangement of six hands per bunch applied to two harvesting stages of Rastali banana fruit development (week 11 and week 12 after emergence of the first hand) × four ripening days (days 0, 1, 3 and 5 after ripening initiated) with three replicates per treatment. Data were analysed using ANOVA (SAS 9.1) and separation of means was carried out using Duncan's multiple range test.

RESULTS AND DISCUSSION

Peel and pulp colour changes

There were significant differences ($P = 0.05$) observed between the interaction of two harvesting periods and days after ripening in peel colour (h° values) and pulp colours (L^*, C^* and h° values) (Table 1). The banana peel changed from green to yellow during ripening for both of the bananas harvested at week 11 (77 days) and 12 (84 days) after emergence of the first hand. However, banana harvested at week 11 showed significantly higher h° values in banana peel colour on days 0, 3 and 5 as ripening progressed (Fig. 1a). This indicated that the peel of banana harvested at a more advanced stage was a more intense yellow in colour as ripening progressed. During ripening, the change of peel colour from mature green to yellow was due to the accumulation of carotenoids and chlorophyll degradation at the thylakoid membrane through chlorophyllase and oxidase enzymes.[16] A similar observation was reported by Ding *et al*.[17] in Cavendish and Berangan bananas.

Banana harvested at week 11 showed significant differences ($P = 0.05$) in pulp colours (L^*, C^* and h° values) compared to banana harvested at week 12 (Table 1). As ripening initiated, banana pulp changed from creamy white to yellow. At day 5 after ripening, banana fruit harvested at week 11 had higher L^* (Fig. 1b) and h° values (Fig. 1d) and lower C^* values (Fig. 1c) in pulp colours compared to banana fruit harvested 1 week later. Thus, Rastali banana harvested at week 11 had lighter and less vivid creamy yellow pulp colour as ripening progressed.

Pulp firmness changes

There was significant interaction between harvesting weeks and days after ripening in pulp firmness as ripening occurred (Table 1). During ripening, pulp firmness decreased by 90.91% and 96.53% as fruit ripened from day 0 to 5 after ripening, respectively, for banana harvested at weeks 11 and 12 (Fig. 2). Banana pulp harvested at week 12 was significantly softer than banana pulp harvested at week 11 on days 0 and 1 after ripening. As fruit ripened, softening occurred which may be due to the breakdown of cells[18] and the conversion of starch to sugars during hydrolysis,[19] resulting in loss of turgidity.

Fruit pH

Fruit pH of Rastali banana harvested at weeks 11 and 12 after emergence of the first hand was not significantly changed as the ripening progressed (Table 1). Rastali banana showed significantly differences as ripening progressed from day 0 to 5. Fruits achieved

Table 1. Physicochemical changes of Rastali banana harvested at two different maturities of harvest, hands and ripening days

	Peel colours			Pulp colours						
Factor	L^*	C^*	h^0	L^*	C^*	h^0	Firmness (N)	pH	CO_2 (mL CO_2 kg^{-1} h^{-1})	C_2H_4 (µL C_2H_4 kg^{-1} h^{-1})
Harvesting weeks (W)										
11	69.59^a	40.38^a	105.52^b	79.16^a	16.13^b	93.97^a	43.40^a	5.38^a	74.23^a	1.19^b
12	69.77^a	39.53^a	107.28^a	78.74^a	17.44^a	94.02^a	32.31^b	5.40^a	59.68^b	1.26^a
Hands (H)										
1	69.23^a	40.28^a	105.57^b	78.61^a	16.93^a	93.75^a	34.97^b	5.22^d	66.91^a	1.75^a
2	69.32^a	40.70^a	106.35^b	79.14^a	16.95^a	94.52^a	35.92^b	5.32^{cd}	64.03^a	1.45^b
3	70.05^a	39.99^a	106.50^{ab}	78.74^a	16.68^a	94.20^a	37.21^{ab}	5.39^{bc}	63.97^a	1.30^{bc}
4	70.50^a	39.31^a	105.92^b	78.84^a	16.80^a	93.96^a	37.98^{ab}	5.39^{bc}	68.99^a	1.36^{bc}
5	69.38^a	39.89^a	106.51^{ab}	79.06^a	16.82^a	93.84^a	39.59^{ab}	5.48^{ab}	68.77^a	1.22^c
6	69.59^a	39.58^a	107.56^a	79.32^a	16.52^a	93.73^a	41.46^a	5.55^a	69.06^a	1.14^c
Days after ripening (D)										
0	62.60^d	37.07^b	119.23^a	79.99^a	16.98^{ab}	95.01^a	64.82^a	5.85^b	45.17^c	0.00e
1	64.24^c	36.79^b	119.16^a	79.68^{ab}	15.98^b	95.16^a	60.54^b	6.00^a	58.69^b	0.25^c
3	77.37^a	42.73^a	95.26^b	78.22^{ab}	17.49^a	93.92^b	21.81^c	5.05^c	85.79^a	2.25^a
5	74.52^b	43.24^a	91.95^c	77.91^b	16.69^{ab}	91.91^c	4.25^d	4.66^d	78.17^a	1.62^b
Interactions										
W × D	NS	NS	†	††	†	†	††	NS	NS	†
W × H	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H × D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W × D × H	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter in the same column are not significantly different by DMRT at $P \leq 0.05$. NS, non-significant difference at $P > 0.05$. Significant difference at † $P \leq 0.05$ or †† $P \leq 0.01$.

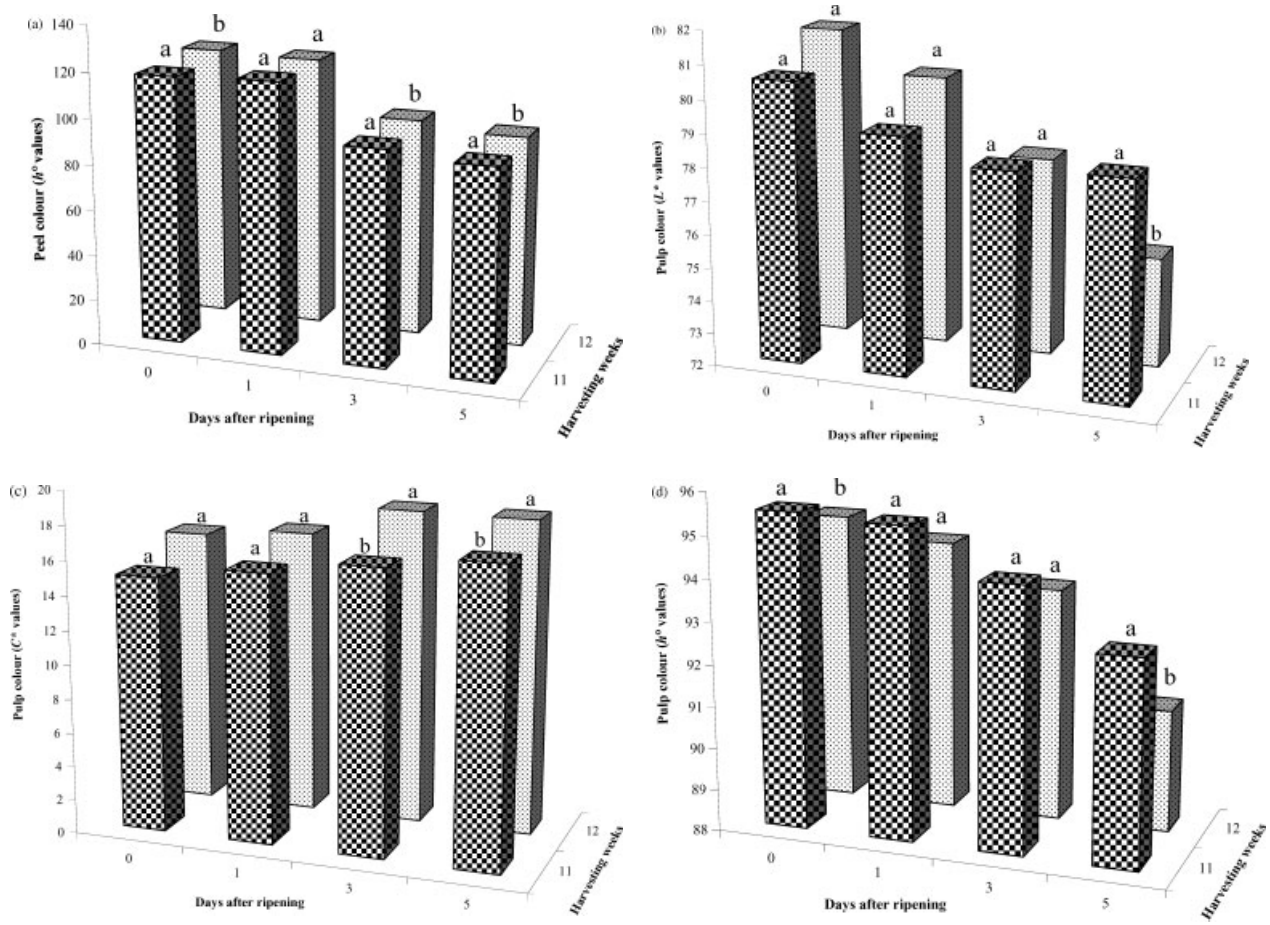

Figure 1. (a) Effects of time (in days) after ripening × harvesting weeks on peel h° values of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by Duncan's multiple range test (DMRT) at $P = 0.05$. (b) Effects of time (days) after ripening × harvesting weeks on pulp L^* values of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by DMRT at $P = 0.05$. (c) Effects of time (days) after ripening × harvesting weeks on pulp C^* values of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by DMRT at $P = 0.05$. (d) Effects of days after ripening × harvesting weeks on pulp h° values of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by DMRT at $P = 0.05$.

Table 2. Sugars content of Rastali banana harvested at 2 maturity stages during ripening (mean ± S.D., n = 6)

	Sugars (g/L)					
	Week 11			Week 12		
Days after ripening (D)	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
0	0.63 ± 0.07	2.83 ± 0.26	6.92 ± 0.60	0.99 ± 0.10	1.55 ± 0.48	7.42 ± 0.11
1	1.20 ± 0.16	4.13 ± 0.46	3.04 ± 0.76	0.55 ± 0.12	6.93 ± 0.96	4.21 ± 0.47
3	5.63 ± 0.88	32.65 ± 4.35	3.33 ± 0.76	11.22 ± 1.49	42.09 ± 4.39	3.14 ± 0.72
5	17.42 ± 2.89	53.34 ± 4.68	3.07 ± 0.22	18.37 ± 1.06	57.68 ± 4.25	2.78 ± 0.65

their highest pH (i.e. 6.00) on day 1 after ripening; thereafter the pH decreased significantly by 15.83% and 7.72%, respectively, as fruit ripened from day 1 to day 3, and day 3 to day 5 (Table 1). This indicated that more ionic hydrogen was dissociated from the carboxyl group (–COOH) of organic acid and released from the fruit as ripening progressed.[20] Organic acids were utilised as respiratory substrates and as carbon skeleton from their carboxyl groups, –COOH for the synthesis of new compounds, such as those that contribute to the flavour, during ripening.[21]

Sugars and organic acids content

Fructose, glucose and sucrose were the three major soluble sugars found in Rastali banana, which contained the highest level of glucose during ripening (Table 2). However, fructose and glucose levels were higher in fruits harvested at week 12 compared to week 11 after emergence of the first hand. Glucose and fructose levels increased as ripening progressed from day 0 to 5. Glucose and fructose were at the highest levels at day 5 after fruit ripening. The sucrose level decreased

Table 3. Organic acids content (g L^{-1}) of Rastali banana harvested at two maturity stages during ripening (mean ± SD, $n = 6$)

	Week 11			Week 12		
Days after ripening (D)	Malic	Citric	Succinic	Malic	Citric	Succinic
0	0.54 ± 0.23	1.77 ± 1.16	1.27 ± 0.57	0.62 ± 0.15	1.71 ± 0.70	1.89 ± 0.96
1	0.35 ± 0.07	2.08 ± 1.29	0.86 ± 0.26	0.37 ± 0.05	2.19 ± 1.08	1.05 ± 0.12
3	1.78 ± 0.14	1.16 ± 0.81	1.17 ± 0.21	2.03 ± 0.24	1.25 ± 0.68	1.13 ± 0.20
5	6.71 ± 0.87	0.19 ± 0.05	0.40 ± 0.07	6.93 ± 0.75	0.34 ± 0.23	0.67 ± 0.13

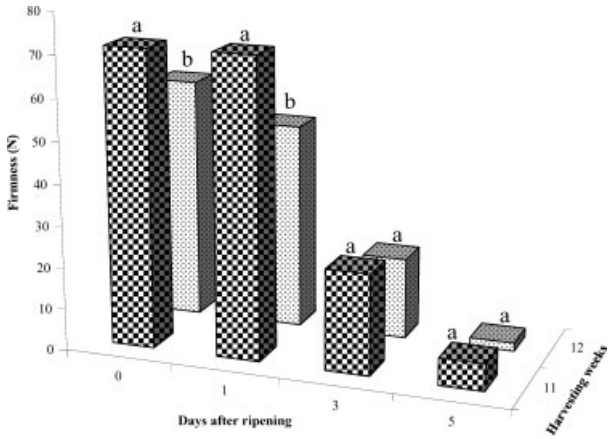

Figure 2. Effects of days after ripening × harvesting weeks on pulp firmness of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by DMRT at $P = 0.05$.

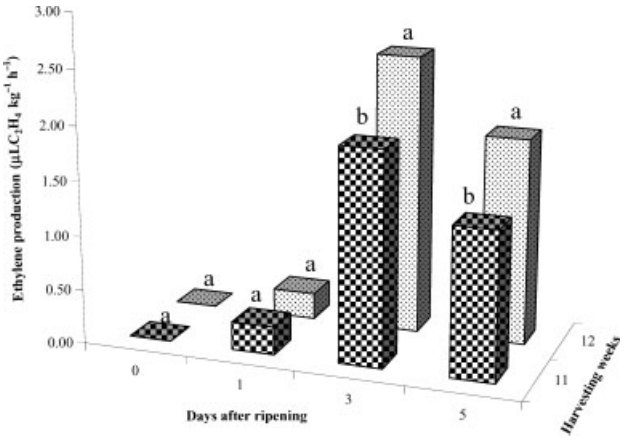

Figure 3. Effects of days after ripening × harvesting weeks on ethylene production of Rastali banana. Mean separations pertaining to each day after ripening followed the same letter in the same column are not significantly different by DMRT at $P = 0.05$.

as ripening developed and achieved the lowest at day 5 for fruits harvested at both week 11 and week 12 (Table 2). The remarkable increase in total sugars observed during the ripening phase of Rastali banana may be attributed to the increase in starch hydrolysis or sugar conversion.[22] Starch-degrading enzymes, such as α-amylase, β-amylase, α-glucosidase and starch phosphorylase were found in isolated banana pulp and the activity of these enzymes increased during ripening.[23] Thus, more starch was degraded by the increased activities of these enzymes, resulting in sweeter banana fruits as ripening progressed.

The major organic acids of Rastali banana harvested at weeks 11 and 12 after emergence of the first hand were malic, citric and succinic and these changed during ripening (Table 3). The levels of citric and succinic acids decreased and reached the lowest in content as fruits ripened at day 5 for bananas harvested at weeks 11 and 12. However, the level of malic acid increased as ripening progressed from day 0 to 5 for both of the banana harvested at two different stages of maturity (Table 3). The decrease of organic acids such as citric and succinic in Rastali banana may be due to the utilisation of organic acids in the tricarboxylic acid cycle, for respiration and sugar conversion.[24] An increase of malic acid and decrease in citric acid were found similarly in persimmon during maturation and ripening.[25] Malic acid was found to be the major organic acid contributing to the acidity not only in Rastali banana but also in plum, peach, apricot and nectarine during ripening.[26] Accumulation of malic acid was also observed in sweet cherry during ripening.[27]

Respiration rate and ethylene production

Rastali banana harvested at a more mature period produced more CO_2 than banana harvested at earlier maturity (Table 1). Respiration rates were low in unripe bananas and increased by 89.93% from day 0 until a peak occurred at day 3 after ripening. Thereafter, the respiration rate decreased by 8.88% as ripening progressed from day 3 to day 5 (Table 1). In this study, Rastali banana showed a significant difference in ethylene production for the interaction among harvesting weeks and days after ripening (Table 1). Ethylene production started at day 1 after ripening initiation and Rastali banana harvested at a more mature stage (week 12) showed significantly higher ethylene production than banana harvested at week 11 at days 3 and 5 after ripening. Ethylene production remained low at day 1 and increased drastically by 650% and 962.5% as fruit ripening progressed from day 1 to day 3 for banana harvested at week 11 and week 12, respectively. After fruits had achieved peaks at day 3, ethylene production decreased by 30.77% for banana harvested at week 11 and 26.27% for banana harvested at week 12 at day 5 as fruits entered the senescence stage (Fig. 3).

In this study, Rastali banana showed significantly higher ethylene emission at week 12 compared to week 11. This result was further support by Zauberman and Schiffman-Nadel[28] and Adato and Gazit[29] with less ripening time being required with increasing maturity of a fruit. The reduction in ripening time in response to increased maturity could be related to ethylene production. A more mature fruit produces more ethylene, which is also believed to accelerate the induction to fruit ripening and

causes fruit to ripen faster. Fruits such as banana, avocado, tomato and melon showed climacteric characteristics with a sudden rise in ethylene production during ripening[30] and it decreased as ripening progressed and reached the senescence stage.[31]

CONCLUSION

In conclusion, Rastali banana fruit was classified as climacteric on the basis of respiration rate and ethylene production during ripening with the peaks of both CO_2 and ethylene production occurring simultaneously at day 3 after ripening was initiated and declined at day 5 when fruits entered the senescence stage. However, banana harvested at week 12 achieved higher ethylene peak than banana harvested at week 11 and this indicated that banana at week 12 ripened and reached the senescence stage faster than banana at week 11. De-greening was observed in both of the bananas harvested at weeks 11 and 12 after the emergence of the first hand and a climacteric rise in respiration and ethylene production during ripening was associated with changes in peel colour from green to yellow, tissue softening, and the fruits becoming more acidic and sweeter as ripening progressed.

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