ELSEVIER

Food Chemistry 75 (2001) 131–137

Food Chemistry

www.elsevier.com/locate/foodchem

Physico-chemical changes in sugarcane (*Saccharum officinarum* var *yellow cane*) and the extracted juice at different portions of the stem during development and maturation

Hanan Yassin M. Qudsieh [a], Salmah Yusof [a,*], Azizah Osman [b], Russly Abdul Rahman [a]

[a] *Department of Food Technology, Faculty of Food Science and Biotechnology, Universiy Putra Malaysia, 43400 UPM Serdang Selangor DE, Malaysia*

[b] *Department of Food Science, Faculty of Food Science and Biotechnology, Universiy Putra Malaysia, 43400 UPM Serdang Selangor DE, Malaysia*

Received 3 May 2000; received in revised form 24 October 2000; accepted 24 October 2000

Abstract

A study was conducted to determine the physicochemical differences between portions (top, middle, and bottom) of sugarcane at different maturation stages (between 3 and 10 months from planting). The variety used was *Saccharum officinarum* var. *Yellow cane*. The parameters analysed were weight, diameter, yield, total soluble solids (TSS), pH, titratable acidity, sugar content (sucrose, glucose, fructose). The weight, diameter, total soluble solids (TSS) and sucrose content increased significantly ($P < 0.01$) in all portions (top, middle and bottom) up to the end of maturity. On the other hand, titratable acidity (TA), pH, juice yield, glucose and fructose contents decreased significantly ($P < 0.01$) during maturation. However, significant differences were also detected in weight, diameter, TSS, sugar content, pH, TA and juice yield between the different portions during maturation. Sucrose content, juice yield and TSS were found to be the most suitable indicators of maturity, while TA, glucose and fructose contents were found to be poor maturity indicators. A suitable harvesting stage was found to be between 7 and 8 months after planting.

1. Introduction

Sugarcane, *Saccharum officinarum*, of the yellow cane variety, is the most popular sugarcane cultivar grown for juice production in Malaysia (Salunkhe & Desai, 1988). Locally it is known as "Tebu kuning" or yellow cane. Among the varieties grown, namely Tebu Betong, Tebu Hitam, Tebu Jalur, Tebu Kapar, Tebu Kuku, Tebu Merah, the yellow variety is most popular because it produces abundant juice and less fibre and has good flavour (Siti & Baharuddin, 1994). Stalks of yellow cane are usually bigger and softer than other varieties and are the most suitable for juice extraction (Tan, 1989). Cane maturity during harvesting is an important factor that affects the taste quality of sugarcane juice (Arceneaux, 1935; Rao & Negi, 1977). Good quality juice has a high proportion of solids to water (^{0}Brix). The highest solute proportion in sugarcane juice is sucrose (Lakshmikantham, 1983).

Earlier studies (Humbert, 1968) showed that the content of reducing sugar decreased during maturation while sucrose increased. According to Lakshmikantham (1983) the yield and quality of sugarcane juice differed significantly with the age at harvest. Thus, maturity index is considered as one of the most important quality determination factors. It serves as a guide in estimating the right maturity stage for harvesting (Salunkhe & Desai, 1988). To date, there is practically no published information regarding the physical and chemical changes in yellow cane (tebu kuning) during its development and maturation. Therefore, this study was conducted to determine the physical and chemical changes of yellow cane during the different maturity stages and the quality

* Corresponding author. Fax: +60-3-8942-3552.
E-mail address: salmah@fsb.edu.my (S. Yusof).

0308-8146/01/$ - see front matter
PII: S0308-8146(00)00294-6

of juice obtained from it at different stem portions (top, middle and bottom). From the results it may be possible to decide on the stage of maturity suitable for juice extraction.

2. Materials and methods

2.1. Samples source

Sugarcanes were obtained from a farm in *Semenyih*, *Selangor*. Eight hundred sugarcane plants were tagged randomly after 1 month of planting. Samples were harvested monthly, starting from 2 months after tagging.

2.2. Sampling

Three samples were obtained randomly for physical and chemical analysis. During harvesting, the tagged canes were cut as close as possible to the base. The top green leaves were removed. The harvested stems were immediately transported to the laboratory at the Faculty Food Science and Biotechnology, UPM. Upon arrival at the laboratory, the canes were cleaned and cut into three equal portions, according to the number of internodes, which are later referred to as top, middle and bottom portions. The experiment was performed in triplicate.

2.3. Extraction of juice (preparation of sugarcane juice)

Before extraction of juice, the canes were cleaned and washed to remove dirt and foreign particles from the surfaces. A three-roller power crusher was used to extract the juice. The juice was then filtered using a four-layer muslin cloth and chilled immediately at 4°C to slow down physical and chemical changes.

2.4. Physical analysis

For physical analysis, weight and diameter of canes and yield of juice were determined according to the methods described by Abdullah, Rohaya and Zaipun (1985). For weight determination, each portion of the cane was weighed individually using a top pan balance (Model 4000C). The diameter measurements were taken at four different parts of each portion using a vernier caliper (Model Mitutoyo). The extracted juice was weighed and the percentage yield was calculated as follows:

$$\text{Percent yield } (\%) = \frac{\text{Weight of juice}}{\text{Weight of stem}} \times 100$$

All physical parameters were determined on the same day after harvesting.

2.5. Chemical analysis

Samples, which were used for the determination of the physical characteristics, were again used to extract the juice for chemical analysis. The types of analysis carried out were total soluble solids, pH, titratable acidity, and sugar. Chemical analyses were carried out on the day of harvesting, except for sugar analysis, which was done on the following day after the juice was frozen at −20°C.

2.6. Total soluble solids

Total soluble solids (TSS) content of juice was determined by using a portable Otago Hand Refractometer (0-32 ^{0}Brix) and the values were expressed as ^{0}Brix.[9]

2.7. Determination of titratable acidity

Titratable acidity (TA) was determined by titrating 10 ml of the juice with 0.1N of NaOH using phenolphthalein as an indicator (AOAO, 1980). The result was expressed as percent of citric acid.

2.8. Determination of pH

The remaining sample after the determination of titratable acidity was used to measure pH. The pH was measured, according to Rangana (1977), using a digital pH meter model CD 720WPA. Buffers of pH 4.0 and 7.0 were used to standardize the equipment.

2.9. Determination of sugar

Sucrose, glucose and fructose were determined by High Performance Liquid Chromatography (HPLC) (Hunt, Jackson, Mortlok & Kirte, 1977). The equipment used was a Waters 600 controller liquid chromatograph with an RI detector, model 410, a Hibar prepacked stainless-steel column (300×3.9 mm), packed with 10 μm Bondapak-NH_2, with acetonitrile and distilled water (80:20; v/v) as eluent. The solvent mixture was degassed for 20 min under a sonicator. Fructose, glucose and sucrose (1–5% w/v) were used as calibration standards. Ten ml of sugar cane juice were made up to 100 ml in a volumetric flask. The solution was then filtered through a Sep-Pak C18 cartridge and a 0.45 μm membrane filter, using a syringe. The injection volume was 20 μl.

2.10. Statistical analysis

The data obtained were analyzed by the Analysis of Variance (ANOVA) and significant differences were determined by Duncan's Multiple Range Test using a Statistical Analysis System (SAS, 1985).

3. Results and discussions

3.1. Physical changes during maturation

3.1.1. Yield of juice

The yield of juice recorded was different between the different portions of the cane. Highest yield was obtained from the bottom portion followed by the middle portion and a significantly lower ($P<0.01$) yield was obtained from the top portion. For the different parts, the yield of juice increased with increase in age of the cane up to 5 months, after which the yield gradually declined (Fig. 1). Maximum juice yield was obtained for the bottom portion of the cane (46.2%) followed by middle (44.2%) and top (31.9%) at 5 months old (Table 1). There was no significant difference observed between 6 and 7 months. The yield at 8 months did not differ much from that at 7 months; in fact it decreased by (4.1%). As the age of cane increased from 7 to 9 months, there was a further decrease of 8.4% and 14.4% from 7 to 10 months. There were high significant differences ($P<0.01$) in the yield of juice obtained from the different parts of cane (top, middle and bottom) during maturation. Correlation coefficient between yield and maturity stages showed a high positive correlation ($r^2=0.95$) up to 5 months, followed by negative correlation ($r^2=-0.993$) from 6 to 10 months.

3.1.2. Weight and diameter

There were significant ($P<0.01$) changes in stem weight of yellow cane (Fig. 2) and diameter (Fig. 3) during growth from 3 months to 10 months. At 5 months, the average stem weight was 729.40 g and the average diameter was 37.66 mm. These increased gradually ($P<0.01$) until the end of maturity (10 months), where the average stem weight and diameter were 1014.22 g and 42.57 mm, respectively (Table 1). Munasque and Mendoza (1990) and Yusof and Mohamed (1987) also observed a similar trend in their work with banana and guava fruits. Figs. 2 and 3 show that the bottom part of the cane was significantly ($P<0.01$) higher in weight and diameter, which continued to increase during the period under study. From Table 1, it can be seen that the bottom portion had the highest weight and diameter (959.89 g, 42.08 mm) followed by the middle (784.15 g, 39.97 mm) and the top (598.20 g, 35.55 mm). Positive correlation ($r^2=0.69$ and $r^2=0.65$) was observed

Table 1
Mean values and standard deviations (±) for yield, weight and diameter of yellow cane during development and maturation[a]

Main effect	Yield of juice (%)	Stem weight (g)	Stem diameter (mm)
Maturity stage (months)			
3	39.33±10.29cd	333.93±80.85g	33.68±1.91h
4	43.49±8.46b	693.48±134.5f	36.70±3.41g
5	44.64±7.34a	729.24±145.0e	37.66±3.26f
6	43.09±6.22ab	765.40±162.2d	39.36±3.77e
7	41.73±6.78b	818.71±233.6c	40.34±2.72d
8	40.01±7.30c	899.31±196.9b	41.36±2.91c
9	38.21±6.00d	991.69±208.4a	41.96±2.75b
10	35.61±5.30e	1014.22±215.8a	42.57±2.56a
Portion of stem			
Top	31.90±5.69c	598.20±157.2c	35.55±2.85c
Middle	44.24±3.72b	784.15±221.6b	39.97±3.49b
Bottom	46.18±4.02a	959.89±279.3a	42.08±3.16a

[a] Means in the same column followed by the same letter are not significantly different at 1% level ($P<0.01$). Each value represents the average for nine different samples.

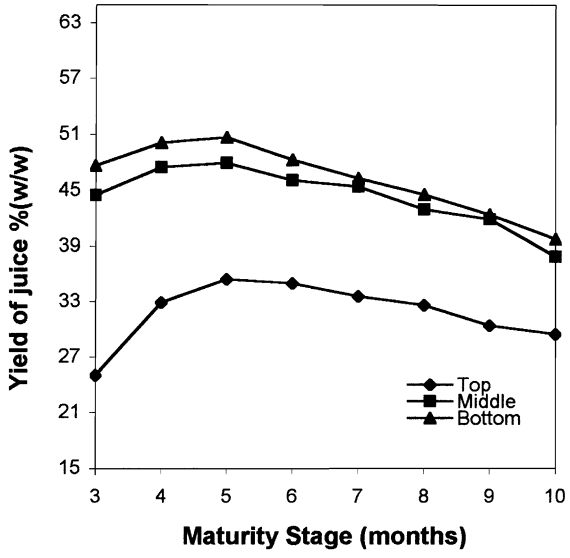

Fig. 1. Changes in juice yield of yellow cane from different portions harvested at different stages of maturation.

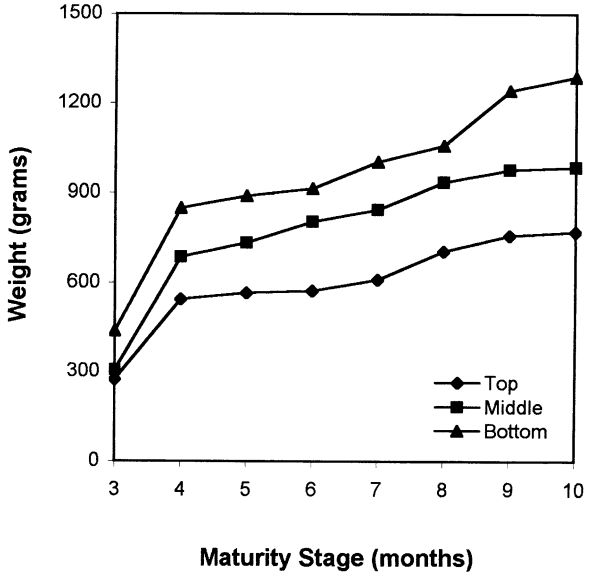

Fig. 2. Changes in stem weight of yellow cane from different portions harvested at different stages of maturation.

between stem weight and diameter, respectively during maturation. Stem weight was also positively correlated ($r^2 = 0.88$) with stem diameter. The same observation was reported by Babu and Khairwal (1975) in their work with sugarcane. On the other hand, weight and diameter were negatively correlated ($r^2 = -0.65$ and $r^2 = -0.50$, respectively) with the yield of juice during maturation.

3.2. Chemical changes during maturation

3.2.1. TSS

There was a highly significant difference ($P < 0.01$) between the TSS contents of sugarcane juice from different portions of cane at different stages of maturation (Fig. 4). In general, the TSS increased from the early stages (3rd to 4th months) until 9 months. Similar results were obtained by El Bulk, Babiker and El Tinay (1997) in guava juice. However, on average, at the 6th and 7th months, the average TSS values were 10.2 ^{0}Brix and 10.3 ^{0}Brix, respectively (Table 2). These values were found not to be significantly ($P > 0.05$) different. TSS continued to increase to 14.1 ^{0}Brix until the 9th month then decreased to 13.8 ^{0}Brix at the end of the maturity. The decrease in TSS was accompanied by an increase in acidity which was caused by the decrease in pH at the end of maturity.

Table 2 shows a highly significant difference ($P < 0.01$) in the TSS between the different stem portions. On average, the TSS value of the bottom was the highest (11.5 ^{0}Brix), followed by the middle (11.0 ^{0}Brix) and then the top (9.4 ^{0}Brix). This result is in agreement with those obtained by Van Dillewijn (1962) and Alexander (1973). They studied TSS distribution in sugar cane stalks and found lower TSS and sucrose content in the top portion of the sugar cane stalk. TSS was correlated positively ($r^2 = 0.897$) with maturation stages. Therefore, TSS was found to be an indicator of sugar cane maturity. Salunkhe and Desai (1988) also reported that TSS was found to be the simplest and cheapest method for determining cane maturity.

3.2.2. TA

Activity decreased during maturation up to 8 months (Fig. 5) and then increased at the end of maturation.

Table 2
Mean values and standard deviations (±) for total soluble solids (TSS), titratable acidity (TA) and pH of yellow cane juice during development and maturation[a]

Main effect	Total soluble solids (^{0}Brix)	Titratable acidity (% of citric acid)	pH
Maturity stage (months)			
3	7.66±1.00e	0.071±0.002a	5.49±0.11a
4	9.12±0.83d	0.0048±0.008cd	5.35±0.05b
5	9.26±0.87c	0.0043±0.009de	5.340±0.05b
6	10.21±1.28c	0.039±0.008e	5.22±0.16c
7	10.31±0.92c	0.038±0.007e	5.19±0.07c
8	10.93±1.30b	0.041±0.006e	5.47±0.08a
9	14.18±1.45a	0.053±0.01a	5.22±0.45c
10	13.87±1.15a	0.049±0.007bc	5.45±0.39a
Portion of stem			
Top	9.48±1.97c	0.055±0.021a	5.29±0.37b
Middle	11.07±2.29b	0.046±0.01b	5.37±0.12a
Bottom	11.53±2.45a	0.041±0.01c	5.35±0.12a

[a] Means in the same column followed by the same letter are not significantly different at 1% level ($P < 0.01$). Each value represents the average for nine different samples.

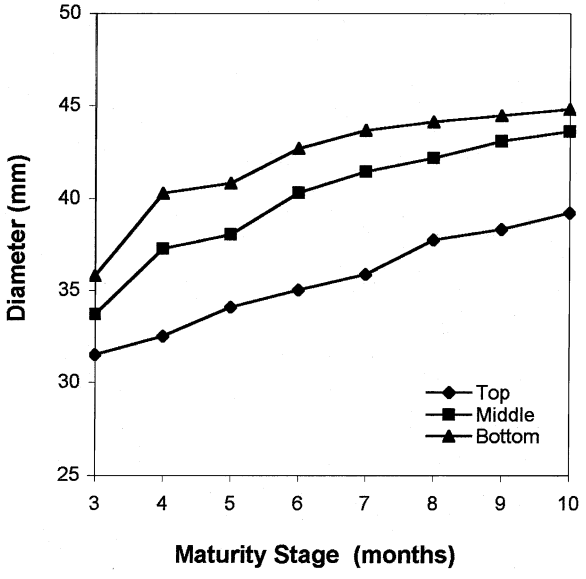

Fig. 3. Changes in stem diameter of yellow cane from different portions harvested at different stages of maturation.

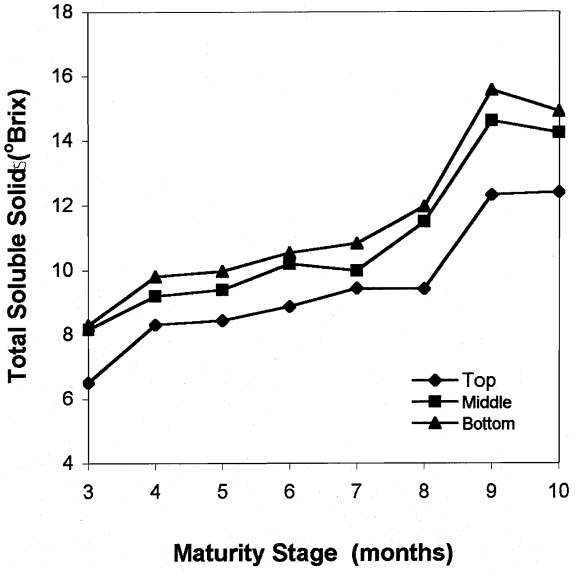

Fig. 4. The total soluble solid of yellow cane juice from different portion harvested at different stages of maturation.

This agrees with the results obtained by Lakshmikantham (1983), who observed that the acidity in immature cane was higher than in mature cane. This trend was also observed by Patel and Katrodia (1994) on sapota fruit. The increase in titratable acidity at a later stage, could be due to breakdown of sugars to acid as the sugarcane became mature. Yusof, Mohamed and Abu Bakar (1988) observed a similar phenomenon with guava fruit. There was a highly significant difference ($P<0.01$) in titratable acidity of sugarcane juice from different portions at different stages of maturity. There were also significant differences ($P<0.01$) in TA values of sugar cane juice between the different portions (top, middle and bottom; Table 2). However, there were no significant differences in TA values at the optimum harvest period of 7 to 8 months (0.038–0.041%). The TA values were also found to be the lowest during this maturation period. In the present study, it was found that the average TA value of the top portion was the highest (0.055%), followed by the middle (0.046%) and bottom (0.041%; Table 2).

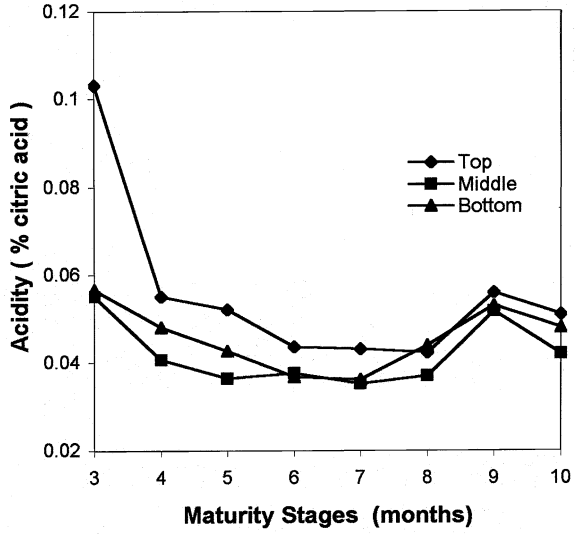

Fig. 5. Titratable acidity of yellow cane juice from different portion harvested at different stages of maturation.

3.2.3. pH

There were highly significant differences ($P<0.01$) in pH readings observed from the different portions of cane at different maturity stages (Fig. 6). The pH decreased in all portions until the 9th month, followed by an increase at the end of maturation (10 months). This trend was also reported by Aziz and Salmah (1994) in their work with soursop. However, there were no significant difference between 6 and 7 months (pH 5.224 and 5.915). There was no significant difference in pH values between the middle and the bottom portions of cane juice (Table 2). The top portion had the lowest pH (5.29), then the middle (pH 5.3) and finally the bottom (pH 5.37). Chen (1985) reported that the pH of the mature sugarcane juice ranges from 5.2 to 5.4. However, almost no relationship ($r^2=0.07$) was observed between pH and maturity stages. There was also very low correlation ($r^2=0.149$) observed between pH and acidity; therefore, the pH values could not be considered as indicators of maturity.

3.2.4. Sugar content

There was a highly significant difference ($P<0.01$) in the sugar contents (fructose, glucose and sucrose) of juice extracted from the different stem portions at different maturation stages (Figs. 7–9). Fructose and glucose

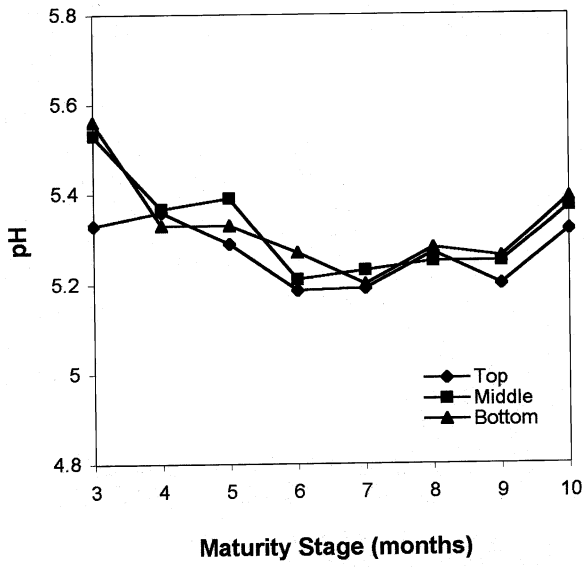

Fig. 6. The pH changes in yellow cane juice from different portion harvested at different stages of maturation.

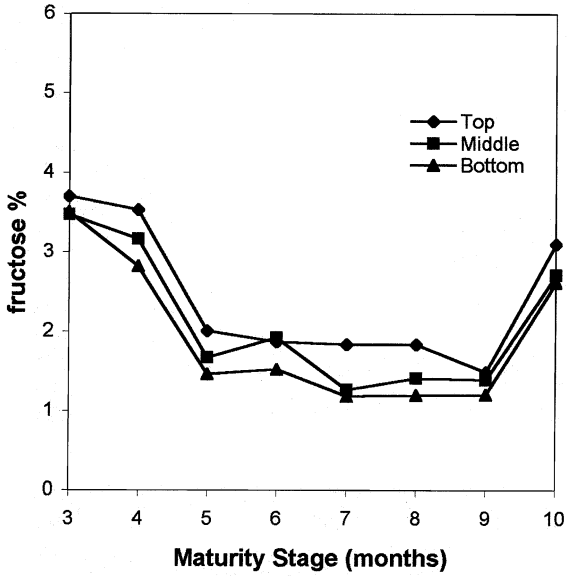

Fig. 7. Fructose content of yellow cane juice harvested at different stages of maturation.

decreased rapidly ($P < 0.01$) at early stages and then decreased slowly during maturation. According to Chen (1985) glucose and fructose contents of sugarcane juice were high in the early harvesting season but decreased as the stalks grew older. From the results (Fig. 8) the value for glucose was higher than that for fructose for all the portions (Table 3). This is in agreement with the work of Sivasubramanian and Pai (1994) on juice of sugarcane Co419 variety. The sucrose content increased gradually from early growth up to maturation from 3 to 8 months (4.95–7.19%), followed by a marked increase at the 9th month (12.9%). These results are in agreement with those of Myhari, Karkalas and Taylor (1999), who reported that sucrose content of Omani dates increased during maturation.

In immature tissue of sugarcane, accumulated sucrose is rapidly hydrolyzed by vacuolar acid invertase to hexoses, which move freely to the cytoplasm for use in growth processes (Salunkhe and Desai, 1988). Also, in mature stalk tissue, when the growth processes have practically ceased, there is a striking decline of vacuolar acid invertase and neutral invertase becomes predominant. In very mature tissues, sucrose is further replaced in the intercellular spaces (Salunkhe and Desai, 1988).

In our own results, at the end of maturity (10th month), there was a decrease in sucrose content. This was accompanied by a rapid increase in glucose and fructose contents. This decrease in sucrose content was perhaps due to the increase in TA values at the 10th month. The increase in titratable acidity could be due to breakdown of sugars to acid as the canes became more mature. This finding is similar to that of Yusof et al. (1988) on guava fruits.

There were also a significant difference ($P < 0.01$) in sugar content of juice from different portions (top, middle and bottom; Table 3). The juice from bottom and middle portions had the highest sucrose contents (8.7 and 7.75%, respectively) but the lowest fructose and glucose contents (1.94 and 2.21%, respectively). Table 3 shows that the top portion had the lowest sucrose content (5.95%) but it produced the highest fructose (2.45%) and glucose (3.86%) contents. A similar trend was also reported by Celestine-Myrtil and Parait (1987) and Branes (1974) for B47258 and B69566 sugar cane varieties. The reason for the high content of sucrose in the bottom portion is that the sugar is not being utilized for growth as in the top portion. This results in the top portion being less sweet. According to

Table 3
Mean values and standard deviations (±) for the percentages of fructose, glucose and sucrose of yellow cane juice during development and maturation[a]

Main effect	Fructose (%)	Glucose (%)	Sucrose (%)
Maturity stage (months)			
3	3.61±0.14a	7.87±0.77a	4.95±1.04f
4	3.44±0.65b	3.71±0.64c	5.34±1.25ef
5	1.71±0.25d	2.70±0.21d	5.35±1.35ef
6	1.77±0.47d	2.69±0.50d	5.67±1.31de
7	1.42±0.32e	1.22±0.36f	6.10±1.16d
8	1.48±0.35e	2.29±0.39e	7.19±1.78c
9	1.35±0.15e	2.12±0.20e	12.9±2.22a
10	2.81±0.23c	6.41±0.77b	12.2±2.40b
Portion of stem			
Top	2.45±0.90a	3.86±2.20a	5.95±2.4c
Middle	2.21±0.99b	3.49±1.97b	7.75±3.70b
Bottom	1.94±0.88c	3.52±2.47b	8.70±3.55a

[a] Means in the same column followed by the same letter are not significantly different at 1% level ($P < 0.01$). Each value represents the average for nine different samples.

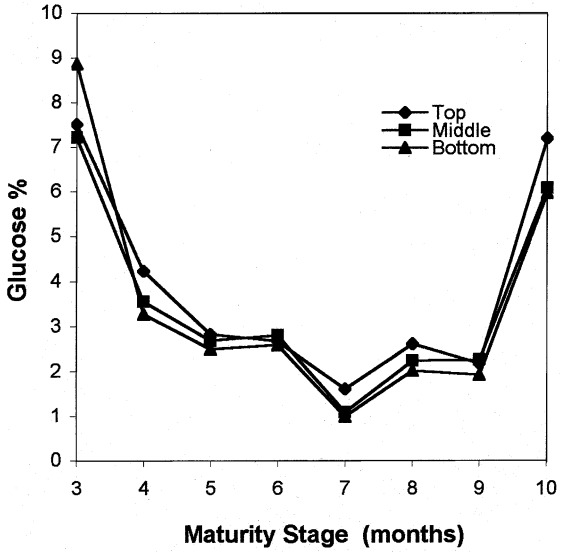

Fig. 8. Glucose content of yellow cane juice harvested at different stages of maturation.

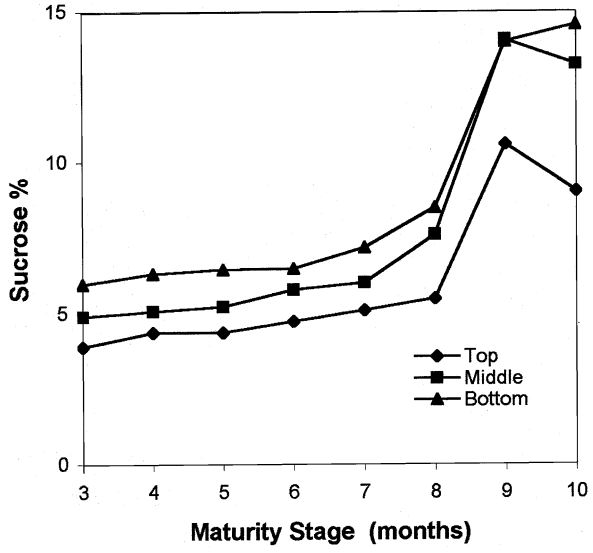

Fig. 9. Sucrose content of yellow cane juice harvested at different stages of maturation.

Salunkhe and Desai (1988), in natural ripening the older internodes (bottom) continue to store sucrose earlier than the younger ones (top portion).

High positive correlation ($r^2 = 0.75$) was observed between sucrose content and maturity stages. Sucrose content was also found to be positively correlated ($r^2 = 0.87$) with TSS. However, glucose and fructose contents were positively correlated ($r^2 = 0.80$) during maturation. On the other hand, glucose and fructose contents were negatively correlated ($r^2 = 0.25$ and $r^2 = 0.49$, respectively) with maturation stages. Nevertheless, no relationship was observed between sucrose content and tiratable acidity during maturation while a positive correlation ($r^2 = 0.49$ and $r^2 = 0.43$) was observed between both glucose and fructose contents and titratable acidity. This correlation explains the increase in reducing sugar found at the early and end stages of maturation.

4. Conclusion

During growth and maturation of sugar cane (var. Yellow cane), there were significant ($P < 0.01$) differences between the physicochemical characteristics of different stem portions (top, middle and bottom) (cane and juice). There were gradual increases in namely weight and diameter. The TSS and sucrose content increased during maturation, while TA, pH, fructose, glucose, and juice yield decreased during maturation. Based on the physicochemical changes, it is suggested that the optimum harvesting stage of sugar cane is between 7 and 8 months after planting. If the sugar canes were to be harvested after 8 months, the juice yield would be lowered significantly ($P < 0.01$) and this would be less economical. The juices from the middle and bottom portions were found to be higher ($P < 0.01$) in sucrose content and TSS ($P < 0.01$) and lower in acidity ($P < 0.01$) than the top portion. Highest yields of juice were obtained from these portions. From this study, a good index of maturity for sugarcane could either be TSS or sucrose content.

Acknowledgements

The authors are grateful to the Ministry of Science, Technology and Environment for providing the funds to Universiti Putra Malaysia to carry out this work.

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