Determination of sugars composition in abscission zone of oil palm fruit

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Abstract. Fresh oil palm fruit bunches (FFB) arriving at a palm oil mill are graded manually and randomly for ripeness classification by counting the number of empty fruit sockets (EFS) found in each bunch before processing. FFBs with at least ten EFS are classified as ripe bunch, FFBs with less than ten EFS are classified as under-ripe, while bunches without any EFS are classified as unripe. The aim of the present study is to determine the composition of sugars in the abscission of these three groups of FFBs by monitoring their sugars composition. The bunches were grouped according to the number of empty fruit sockets: (i) nil; (ii) 1-9; (iii) ≥10 as unripe, under-ripe and ripe bunches, respectively. Non-structural, structural and water-soluble sugars extracted from the abscission zone were analyzed. The principal component analysis (PCA) based on various sugars compositions revealed some natural clustering among the samples. Bunches with more than one empty fruit sockets were distinguished from the others using glucose, sucrose and oligomers. In conclusion, analysis of sugars composition of the abscission zone could potentially be used as a chemical marker to differentiate those bunches at different stages of ripeness.

1. Introduction
In oil palm plantations, the detachment and fall of the ripe fruit from its oil palm fruit bunch is taken as an indication of readiness for harvesting [1, 2, 3]. Additionally, the change of mesocarp color is also used as another indicator [2, 3, 4]. Orange bunches are classified as ripe while purplish or yellowish bunches are classified as unripe or under-ripe. Precise determination of ripeness is important during harvesting because milling of unripe and under-ripe bunches results in a lower oil extraction rate while over-ripe bunches reduce the quality of palm oil produced [4, 5]. In palm oil mills, fresh fruit bunches (FFBs) are checked randomly via visual inspection and counting the numbers of empty fruit sockets (EFS) per bunch by the experienced grader on duty. According to Malaysian Palm Oil Board (MPOB), FFBs with at least ten EFS are classified as ripe bunch, FFBs with less than ten EFS are classified as under-ripe, while bunches without any EFS are classified as unripe [6]. Therefore, the present study is to find out the difference amongst these three groups of FFBs by monitoring their sugars composition.
Colorimetry approaches such as ultraviolet-visible photometric [2, 5, 7, 8, 9, 10], near infrared spectroscopic [11] and multi-parameter fluorescence sensor [12] were investigated to classify the ripeness of FFBs. Other researchers, taking the metabolomics approach, revealed the changes in amino acids, organic acids, sugars and nucleosides [13, 14], lipid content [13, 15, 16] and polyamines [17] during the oil palm fruit development. [17, 18, 19, 20] reported that the transcription factors expressed might lead to the identification of ripening. These studies monitored the controlled samples collected from 12 to 24 weeks after anthesis. No study has sought a profiling pattern between these characteristics and the manual ripeness determinations of FFBs delivered to the palm oil mill. The characteristics of FFBs delivered to the mill might be different from those of controlled bunches from trial plot because of a certain degree of damage due to the handling during transportation [21].

Fruit ripening is reported to associate with biochemical changes in cell wall materials such as cellulose, hemicellulose and pectin via hydrolytic processes [22, 23]. The chemical changes, especially at the abscission zone have been found to result in separation of cells, as well as separation of the fruit from the stalk [24]. The abscission zone is the place from which the oil palm fruit is shed (Figure 1). Hydrolase were suggested to be involved in cell wall degradation might be responsible for co-ordinating the shedding of the oil palm fruit [20, 25]. Younger palm fruits found to exhibit slightly thicker cell walls and middle lamellae at the abscission zone than those mature fruits [24]. Fruit separation is determined by the age or ripeness of the fruits [26].

In this study, the abscission zones of unripe, under-ripe and ripe FFBs were evaluated based on the non-structural, structural and water-soluble sugar contents in the present study. The sugars data obtained were analyzed using chemometric techniques to classify and differentiate according to the ripeness of the FFBs. This information could potentially be used as a reaffirming biochemical transformation to show a similar classification pattern using the empty fruit socket monitoring grading system in palm oil mills.

![Figure 1. Abscission zone (rectangle area) of an oil palm fruit. A, with tepal attached; B, without tepal; C, halve view.](image)

2. Materials and methods

2.1. Fresh fruit bunches
Oil palm fresh fruit bunches (FFBs) were collected from Labu Palm Oil Mill, Labu, Negeri Sembilan. In total, 27 FFBs were collected: 10 ripe (≥ 10 empty fruit socket); 8 under-ripe (1 to 9 empty fruit socket); 9 unripe (no empty fruit socket). The weight of FFBs collected were ranging from 15kg to 45kg. FFBs were cut to obtain the spikelets of aprical (top), equatorial (middle) and basal (bottom)
regions according to [3]. All samples were stored at -80°C until analysis. Samples were thawed and cut to remove the abscission zone [27]. The abscission zone was ground in liquid nitrogen using an IKA Batch Mill A11 Basic (Wilmington, North Carolina, USA) and then freeze-dried with a ScanVac CoolSafe freeze dryer (Lunge, Denmark). The freeze-dried samples were then kept at -80°C prior to analysis.

2.2. Standards and reagents
Analytical grade ethanol was purchased from Merck (Darmstadt, Germany), sulfuric acid and phenol were purchased from Fisher Scientific (Geel, Belgium). Calcium carbonate and sugar standards, namely xylan, sucrose, glucose, xylose, arabinose, galactose, mannose and fructose were purchased from Sigma Aldrich (St Louis, MO, USA).

2.3. Determination of non-structural sugar (NS)
The non-structural sugar (NS) was extracted and analyzed with slight method modification [28]. About 300mg of dried samples were extracted with 5mL of 80% ethanol. An Eppendorf 5355 thermomixer (Hamburg, Germany) was used to maintain the temperature at 40°C with a mixing speed of 750rpm for 10 min. After each extraction, the tubes were centrifuged at 4000rpm for 5 min with an Eppendorf 5810R centrifuge (Hamburg, Germany), the supernatants of three extractions were combined for sugar analysis. Approximately 50µL of solution containing sugar was added with 150µL of distilled water. Approximately 400µL of 2% phenol was added into the diluted sugar solution followed by additional of 1mL concentrated sulfuric acid. The solution was stood in dark for 10 mins and then left in ice water for another 10 mins. About 200µL of brown solution containing sugar derivatives was placed in a 96-well plate and analyzed at 490nm using a BioTek ELx800 microplate reader (Winooski, USA). The sugar content in each sample was quantified against glucose standard solution with concentration ranging from 0.05% w/v to 1.5% w/v.

2.4. Determination of structural sugar (SS)
Structural sugar (SS) extraction was conducted according to the NREL method [29] with slight modification. Approximately 3mL of 72% sulfuric acid was added into the tube containing the residue from the ethanol extraction and vortex for 1 min. The tube was shook at 400rpm at 30°C in a Thermo Scientific MaxQ400 incubator shaker (Waltham, Massachusetts, USA) for 1 hour. After that, about 84mL of purified water was added into the tube. Then, the sample was autoclaved for 1 hour at 121°C. After completion of the autoclave, the hydrolyzed solution was allowed to cool to room temperature. About 12mL of the hydrolyzed solution was transferred to another vial; about 0.6g of calcium carbonate was added slowly to obtain pH 5-6. The total sugar content of supernatant was analyzed at 490nm similar to aforementioned NS procedures.

2.5. Determination of water-soluble sugar (WS)
Approximately 300mg of freeze-dried samples were autoclaved for 1 hour at 121°C. After completion of the autoclave, the samples were extracted with 5mL of water for three times. The supernatants, namely water-soluble sugar (WS) of three extractions were pooled and analyzed at 490nm as per aforementioned NS procedures.

2.6. High performance liquid chromatography (HPLC) analysis
The water-soluble sugar (WS) were filtered at 0.2µm and analyzed the sugar composition using an Agilent 1260 Infinity LC system coupled with 1260 Infinity Evaporative Light Scattering Detector (HPLC-ELSD) (Santa Clara, USA). Separation was carried out using an Aminex HPX-87P column (9µm, 300mm x 7.8mm i.d) purchased from Bio-Rad (Philadelphia, USA). The column was set at 80°C. The temperature of the drift tube and sensitivity of detector were set at 75°C and 5, respectively with nitrogen gas flow of 1.6L/min. Filtered water used as the mobile phase. Total run time was 25 mins. A series of sugar standard solution, consisting of xylan, sucrose, glucose, xylose, arabinose,
galactose, mannose and fructose were prepared in concentration ranging from 0.01 % w/v to 0.3 % w/v.

2.7. Principal component analysis and statistical analysis
The data is expressed as a mean ± standard deviation (SD) of triplicate analyses. All statistical analyses were performed using Microsoft office Excel 2010. Analysis of variance (ANOVA) and significance, defined at P<0.05 were applied. Principal component analysis (PCA) was performed using Simca-P, version 13 (Umetrics).

3. Results and discussion

3.1. Statistical analysis
All values are presented as mean±standard deviation (SD). The data were analyzed using ANOVA. No significant difference was observed between the samples collected from the regions of top, middle and bottom from a bunch. The fruits on a bunch do not ripen simultaneously, with ripening usually begins from the top to the bottom of the bunch [3]. Samples collected in the present study are abscission zone which were also different from those fruit samples from the previous study. Abscission zone containing cell wall hydrolytic enzymes that enhance the degradation of cell wall components for fruit separation, which is different from the adjacent tissues [20]. Abscission zone were found to have no oil body in their cells, that also indicating that abscission zone is different from other cells of a ripe fruit mesocarp [24, 25].

3.2. Non-structural, structural, water-soluble sugars composition
The grading standard implemented in a palm oil mill is based on total numbers of empty fruit socket (EFS), i.e unripe, nil; under-ripe, 1-9 EFS; ripe, ≥ 10 EFS. The bunches collected regardless of the aforementioned ripeness stage, they are ready-to-harvest with maximum oil content. Therefore, in the present study, the sugar content at the abscission zone was used as a chemical marker to distinguish those bunches containing different numbers of empty fruit socket.

The sugars composition, namely non-structural sugar (NS), structural sugar (SS) and water-soluble sugar (WS) of each sample were analyzed and and summarized in Table 1. Sugar-based carbohydrates can be classified as non-structural and structural [29]. The non-structural carbohydrates are the extractive which can be removed using extraction or washing step. On the other hand, structural carbohydrates are those bound in the matrix of the biomass, such as cellulose and hemicellulose. The NS, SS, WS were significantly different due to the differences in the treatment method which resulted in certain degree of hydrolysis of the samples.

From the ANOVA analysis, the data for unripe, under-ripe and ripe bunches were significantly different since the p value <0.05. On the other hand, no difference was observed in between under-ripe and ripe bunches. Therefore, sugars composition, such as NS, SS, or WS could be used to distinguish unripe bunches from those under-ripe and ripe bunches. In addition, NS, SS, or WS could be used to distinguish those FFBs with and without empty fruit socket, because all fruits are intact in unripe bunches while under-ripe and ripe bunches contain at least one detached fruit.

3.2.1. Non-structural sugar (NS) content
The NS content found in abscission zone of unripe bunches were ranging from 1.78% to 3.61% with a mean of 2.47±0.39%. For under-ripe bunches, the NS content of 1.80-3.29% were detected. This also recorded a mean of 2.68±0.37% of NS in under-ripe bunches. On the other hand, about 2.08-3.84% of NS were detected in ripe bunches with a mean of 2.86±0.47%. From the mean value, the highest amount of NS was found in the ripe bunches, followed by under-ripe and then unripe bunches. Water extracted sugar in oil palm was detected as 1.3% w/w at week 23 after pollination [18]. Sugars content detected in the samples of present study was slightly higher as compared to that reported [18], this might due to the FFBs collected in the present study are mostly with slight degree of damage
during transportation from the plantation to the mill. Furthermore, the samples used in the present study were obtained from the abscission zone, which contain mostly the cell wall materials.

Table 1. Sugars composition (% w/v) in FFB samples, namely non-structural (NS), water-soluble (WS) and structural (SS) sugars.

|                   | NS      | WS      | SS      |
|-------------------|---------|---------|---------|
| **Unripe (n = 9)**|         |         |         |
| Top               | 2.452±0.315<sup>bc</sup> | 3.197±0.561<sup>ab</sup> | 5.277±0.644<sup>ab</sup> |
| Middle            | 2.524±0.337<sup>ac</sup> | 3.141±0.478<sup>ad</sup> | 5.229±1.252<sup>ac</sup> |
| Bottom            | 2.424±0.510<sup>bc</sup> | 3.342±0.409<sup>e</sup>  | 4.443±1.009<sup>bc</sup> |
| **Under-ripe (n=8)**|       |         |         |
| Top               | 2.487±0.457<sup>ab</sup> | 3.525±0.531<sup>ab</sup> | 5.929±0.714<sup>ab</sup> |
| Middle            | 2.883±0.314<sup>ac</sup> | 3.469±0.378<sup>ac</sup> | 5.857±0.950<sup>ed</sup> |
| Bottom            | 2.677±0.192<sup>bc</sup> | 3.702±0.611<sup>bc</sup> | 6.291±0.422<sup>ce</sup> |
| **Ripe (n=10)**   |         |         |         |
| Top               | 2.852±0.460<sup>ab</sup> | 3.650±0.578<sup>ab</sup> | 6.048±0.936<sup>ab</sup> |
| Middle            | 2.880±0.534<sup>ac</sup> | 3.723±0.187<sup>ac</sup> | 6.305±0.886<sup>ac</sup> |
| Bottom            | 2.841±0.454<sup>bc</sup> | 3.457±0.417<sup>bc</sup> | 5.767±0.665<sup>bc</sup> |

Means within a column segment followed by different superscript letters (a-e) are significantly different (p<0.05).

3.2.2. Water-soluble sugar (WS)

The water-soluble sugar (WS) obtained after autoclave were found slightly higher than those NS content. The WS content found in abscission zone of unripe bunches were ranging from 2.52% to 4.53% with a mean of 3.23±0.48%. In under-ripe bunches, the WS content of 2.75-4.82% (mean: 3.57±0.51%) were detected in bunches. Besides, about 2.68%-4.68% (mean: 3.61±0.43%) of WS were found in ripe bunches. From the mean value, similar trend of WS was observed, highest WS amount was found in ripe bunches, followed by under-ripe and then unripe bunches. The amounts of WS were found slightly higher than those NS contents, due to the hydrolysis or degradation of cell wall materials that took place during high temperature autoclave before extraction. Elevated temperatures with sufficient water enhanced the hydrolysis of cell wall materials and resulted in the formation of five-carbon and six-carbon simple sugars [24]. In addition, high temperature hydrolysis happened in the palm fruits during sterilization would degrade the semi-stable hemicellulose [24].

In order to confirm the degradation of the cell wall materials, the composition of WS of each sample was analyzed using HPLC-ELSD and quantified based on the calibration curves of respective standards, namely glucose, xylose, arabinose, galactose, mannose and fructose. One of the chromatograms is compared to the standards as shown in Figure 2. Sucrose and glucose were found clearly in the chromatogram, both ranging from 0.34% to 0.54% for all unripe, under-ripe and ripe samples. Higher sucrose (1.3% w/w) than glucose (0.058% w/w) and fructose (0.15% w/w) were found in the ripe oil palm samples [18]. The values found were different from those reported [18], it could be due to (i) different samples (abscission zone vs palm fruits), (ii) different extraction method and (iii) different analytical methods used in both study. Formation of glucose, sucrose and fructose could be due to sucrose catabolism inside the palm fruit before the harvesting [30]. In the present study, no fructose was detected maybe because of the detection limitation of the analytical instrument.
A group of unknown peaks was observed at retention time between 4.5 min to 8.5 min. These peaks were unable to be identified due to lack of standards. The unknown peaks were suspected as the oligo-intermediates by comparing the chromatogram and retention time with the study of Schwald and team [31], they found that the oligomers eluted before glucose and sucrose using similar column and HPLC setting.

Therefore, by assuming the unknown peak is oligo-intermediates, it can be assumed that the hydrolysis did take place during the autoclave to degrade some of the hemicellulose into the smaller oligo-intermediates. However, autoclaving at 121°C for 1 hour was not sufficient to convert them further to simple monomers may be due to insufficient quantity of water and missing acid catalyst. Thus, none of the hemicellulose monomer such as xylose, arabinose and galactose was detected by HPLC-ELSD. Hemicellulose in palm fruits is labile to heat if the heating condition is supplied with sufficient water [24]. In addition, [32], [33], [34] found that the degradation of cell wall materials formed oligo-intermediates before formation of the monomers such as glucose and xylose. Due to the amount of unknown peaks are significant in the chromatogram; therefore, they were quantified as xylan equivalent, as the first unknown peak having the retention time similar as xylan (5 min to 6

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**Table 2.** Sugar composition of WS fraction (% w/v) in FFB samples.

|            | Glucose  | Sucrose  | Unknown     |
|------------|----------|----------|-------------|
| **Unripe** |          |          |             |
| Top        | 0.432±0.065<sup>ab</sup> | 0.416±0.041<sup>ab</sup> | 5.521±1.253<sup>ab</sup> |
| Middle     | 0.437±0.071<sup>bc</sup> | 0.420±0.059<sup>ac</sup> | 5.776±1.260<sup>ac</sup> |
| Bottom     | 0.398±0.055<sup>bc</sup> | 0.392±0.044<sup>bc</sup> | 7.917±2.354<sup>bc</sup> |
| **Under-ripe** |         |          |             |
| Top        | 0.407±0.052<sup>ac</sup> | 0.391±0.036<sup>bc</sup> | 6.657±1.954<sup>ab</sup> |
| Middle     | 0.480±0.089<sup>bd</sup> | 0.444±0.073<sup>bd</sup> | 6.491±2.625<sup>ac</sup> |
| Bottom     | 0.411±0.079<sup>cd</sup> | 0.391±0.069<sup>bd</sup> | 6.968±1.519<sup>bc</sup> |
| **Ripe** |          |          |             |
| Top        | 0.429±0.062<sup>ab</sup> | 0.418±0.047<sup>ab</sup> | 5.578±1.426<sup>ab</sup> |
| Middle     | 0.436±0.066<sup>ac</sup> | 0.423±0.039<sup>ac</sup> | 6.098±1.529<sup>ac</sup> |
| Bottom     | 0.412±0.041<sup>bc</sup> | 0.399±0.033<sup>bc</sup> | 6.954±1.736<sup>bc</sup> |

Means within a column segment followed by different superscript letters (a-e) are significantly different (p<0.05).
The unknown compounds found in unripe, under-ripe and ripe bunches were 6.40±1.97%, 6.71±2.02% and 6.21±1.62%, respectively. Oligomers are hydrolyzed by concentrated sulfuric acid during the phenol-sulfuric assay to form monomers [28]. Therefore, although none of xylose, arabinose, nor galactose was detected by HPLC, but higher amount of water soluble sugar were detected as WS due to the hydrolysis of unknown compounds into reducing sugar.

3.2.3. Structural sugar (SS)
With the addition of sulfuric acid, more sugars in the form of structural sugar (SS) were extracted as a result of more cell wall materials were hydrolyzed. The amount of SS obtained were 2.54% to 7.83%, with a mean of 4.98±1.04% in unripe. About 4.05% to 7.53%, with a mean of 6.03±0.73% of SS were detected in under-ripe bunches. For the ripe bunches, about 4.18-7.42%, with a mean of 6.04±0.84% of SS were detected. From the mean value, higher WS amount was found in ripe and under-ripe bunches as compared to those of unripe bunches. Cell wall materials were hydrolyzed more easily with the aid of acid than with water alone. Hydrothermal treatment was not as good as diluted acid hydrolysis of wood material to produce their respective monomers [34], [35]. This also in agreement with the results of structural sugars obtained in the present study where the structural sugars were found higher than water-soluble sugars.

3.3. Principal component analysis (PCA)
Principal component analysis method or PCA was performed on the autoscaled data matrix, to provide a partial visualization of data structure in order to identify the distribution among the samples with different ripeness. PCA was conducted on the sugars composition data of the 27 FFBs with different ripeness and bunch region of top, middle and bottom. The data matrix consisted of 90 rows and 6 variables (NS, SS, WS, glucose, sucrose, unknown). The 2D scatter plot shown in Figure 3 did not show any cluster present. However, after rearranging it into a 3D plot, the PCA on the data revealed the presence of some natural clustering as shown in Figure 4. The first and second PCA factors together reveals 63% of the variance in the data set. From the PCA scatter plot, samples formed a narrower cluster, ripe samples (green) on top of unripe samples (blue), while under-ripe samples (red) appeared at the bottom along the Num-axis. Although some misclassifications were observed, the output of the PCA plot was very satisfactory. This could be due to certain degree of damage of the samples when transporting from the plantation to the mill. By comparing the PCA scores plots with the loading plots, the component mostly contributed to the separation of the ripeness classification is revealed. The unknown compounds are the chemical markers which are responsible for differentiating the ripe samples from the others. WS components, namely glucose, sucrose present in the unripe samples are markedly different from the WS in the under-ripe and ripe samples. While both non-structural and structural sugars are the factors that differentiate under-ripe samples from the rest as shown in Figure 4.

4. Conclusions
The classification of FFB ripeness by measuring the sugars composition seems feasible to be used as the reaffirming chemical markers to support the ripeness grading system according to the total number of the empty fruit socket that is currently practised in palm oil mills. Sugars composition such as non-structural, structural, or water extract could be used to differentiate in between bunches with loose fruits and those without any loose fruit. Compositions such as glucose, sucrose and unknown compounds could be used to confirm the ripe bunches with at least 10 empty fruit sockets. In combination with chemometrics method namely principal component analysis (PCA), the ripeness classification could be visualised. Our chemometrics approach was based on an unbiased autoscaled classification approach. The present method is interesting as it is able to distinguish the ripeness stage of the oil palm fresh fruit bunches based on the clustering of certain chemicals compounds, thus provides an in-dept understanding of the components of cell at different ripeness stages.
Figure 3. First two factors of the PCA scores plot on the different sugars composition (auto-scaled data) of FFBs with different ripeness, size and bunch region: green, ripe; blue, unripe; red, under-ripe.

Figure 4. 3D PCA scores plot of first two factors on the different sugars composition (auto-scaled data) of FFBs with different ripeness, size and bunch region: green, ripe; blue, unripe; red, under-ripe.

Acknowledgements

We are grateful to Sime Darby Plantation Sdn Bhd and University Putra Malaysia LRGS for granting the project and also thank to Labu Palm Oil Mill for the samples provided and Sime Darby Technology Centre Sdn Bhd for providing the experimental station. We would also like to thank Dr Teh Huey Fang, Dr Umer Rashid, Mohd Zairey and Alena Sanusi for the guidance and editing.

Reference

[1] Ariffin A A, Rosnah M S, Mohamadiah B, Wan Zailan W O and Chen K W 1991 Ripeness standard: any sign of loose fruit and with one loose fruit per bunch on the minimum standard Proceedings of the 1991 PIPOC, Agric Conf, (Bangi:PORIM) pp 120-9

[2] Abdullah M Z, Guan L C and Azemi M 2001 Stepwise discriminant analysis for colour grading of oil palm using machine vision system IChemE 79 223-31
[3] Razali M H, Halim A S M A and Roslan S 2012 A review on crop plant production and ripeness forecasting IAACS 4(2) 54-63
[4] Abdullah M Z, Guan L C, Lim K C and Karim A A 2004 The applications of computer vision system and tomographic radar imaging for assessing physical properties of food J. Food Eng. 61 125-35
[5] Abdullah M Z, Lim C G, Mohamed A M D and Noor M A M 2002 Color vision system for ripeness inspection of oil palm elaeis guineensis J. Food Process Pres. 26 213-35
[6] Malaysian Palm Oil Board (MPOB) 2003 Oil Palm Fruit Grading Manual (2nd Ed.). Kajang: Malaysian Palm Oil Board (MPOB) pp1-47
[7] Shariff R, Adnan N A, Mispan R, Mansor S, Halim R and Goyal R 2004 Correlation between oil content and DN values GISdevelopment.net
[8] Alftati M S M, Shariff A R M, Shafri H Z M, Saaed O M B and Eshanta O M 2008 Oil palm fruit bunch grading system using red, green and blue digital number J. Appl. Sci. 8(8) 1444-52
[9] Sunilkumar K and Babu D S S 2013 Surface color based prediction of oil content in oil palm African J.Agr. Res. 8(6) 564-9
[10] Makky M and Soni P 2013 Development of an automatic grading machine for oil palm fresh fruits bunches (FFBs) based on machine vision Comput. Electron. Agr. 93 129-39
[11] Saeed O M B, Sankaran S, Shariff A R M, Shafri H Z M, Ehsani R, Alftati M S and Hazir M H M 2012 Classification of oil palm fresh fruit bunches based on their maturity using portable four-band sensor system Comput. Electron. Agr. 82 55-60
[12] Hazir M H M, Shariff A R M and Amiruddin M D 2012 Determination of oil palm fresh fruit bunch ripeness based on flavonoids and anthocynin content Ind. Crops Prod. 36 466-75
[13] Neoh B K, Teh H F, Ng T L M, Tiong S H, Thang Y M, Ersad M A, Mohamed M, Chew F T, Kulaveerasingam H and Appleton D R 2013 Profiling of metabolites in oil palm mesocarp at different stages of oil biosynthesis J. Agric. Food Chem. 61(8) 1920-7
[14] Teh H F, Neoh B K, Hong M P L, Low J Y S, Ng T L M, Ithnin N, Thang Y M, Mohamed M, Chew F T, Yusof H M, Kulaveerasingam H and Appleton D R 2013 Differential metabolite profiles during fruit development in high-yielding oil palm mesocarp PLoS ONE 8(4) e61344
[15] Prada F, Ayala-Diaz I M, Delgado W, Ruiz-Romero R and Romero H M 2011 Effect of fruit ripening on content and chemical composition of oil from three oil palm cultivars (Elaeis guineensis Jacq.) grown in Colombia J. Agric. Food Chem. 59(18) 10136-42
[16] Sambanthamurthi R, Sundram K and Tan Y A 2000 Chemistry and biochemistry of palm oil Prog. Lipid Res. 39 507-58
[17] Teh H F, Neoh B K, Wong Y C, Kwong Q B, Ooi T E K, Ng T L M, Tiong S H, Low J Y S, Danial A D, Ersad M A, Kulaveerasingam H and Appleton D R 2014 Hormones, polyamines, and cell wall metabolism during oil palm fruit mesocarp development and ripening J. Agric. Food Chem. 62 8143-52
[18] Bourgis F, Kilaru A, Cao X, Ngando-Ebongue G, Dirra N, Ohlrogge J B and Arondel V 2011 Comparative transcriptome and metabolite analysis of oil palm and date palm mesocarp that differ dramatically in carbon partitioning PNAS 108(30) 12527-32
[19] Tranbarger T J, Dussert S, Joët T, Argout X, Summo M, Champion A, Cros D, Omore A, Nouy B and Morcillo F 2011 Regulatory mechanisms underlying oil palm fruit mesocarp maturation, ripening, and functional specialization in lipid and carotenoid metabolism Plant Physiol. 156 564-84
[20] Roongsatatham P, Morcillo F, Jantasriyarat C, Pizot M, Moussu S, Jayaweera D, Collin M, Gonzalez-Carranza Z H, Amblard P, Tregear J W, Tragoonrung S, Verdeil J and Tranbarger T J M 2012 Temporal and spatial expression of polygalacturonase gene family members reveals divergent regulation during fleshy fruit ripening and abscission in the monocot species oil palm BMC Plant Biol. 12(150) 1-10
[21] Chong C L and Sambanthamurthi R 1993 Effects of mesocarp bruising on the rate of free fatty acid release in oil palm fruits Int Biodeterio Biodegradation 31 65-70
[22] Payasi A, Mishra N N, Chaves A L S and Singh R 2009 Biochemistry of fruit softening: an overview *Physiol. Mol. Biol. Plants* **15**(2) 105-13
[23] Prasanna V, Prabha T N and Tharanathan R N 2007 Fruit Ripening Phenomena–An Overview *Crit. Rev. Food Sci. Nutr.* **47** 1-19
[24] Ariffin A A 1991 Chemical changes during sterilization process affecting strippability and oil quality *Seminar on Developments in Palm Oil Milling Technology and Environmental Management* (Genting Highlands: PORIM) pp 2-12
[25] Henderson J and Osborne D J 1994 Inter-tissue signalling during the two-phase abscission in oil palm fruit *J. Exp. Bot.* **45**(276) 943-51
[26] Henderson J and Osborne D J 1990 Cell separation and anatomy of abscission in the oil palm, Elaeis guineensis Jacq. *J. Exp. Bot.* **41**(223) 203-10
[27] Henderson J, Davies H A, Heyes S J and Osborne D J 2001 The study of a monocotyledon abscission zone using microscopic, chemical, enzymatic and solid state 13C CP/MAS NMR analyses *Phytochemistry* **56** 131-9
[28] Chow P S and Landhäusser S M 2004 A method for routine measurement of total sugar and starch content in woody plant tissues *Tree Physiology* **24** 1129-36
[29] Sluiter A, Hames B, Ruiz R, Scarlata C, Sluiter J, Templeton D and Croker D 2008 Determination of structural carbohydrates and lignin in biomass *Laboratory Analytical procedure* (Colorado: National Renewable Energy Laboratory)
[30] Dennis D T and Blakeley S D 2000 Carbohydrate Metabolism *Biochemistry and Molecular Biology of Plant*, eds B B Buchanan, W Gruissem and R L Jones (Maryland: American Society of Plant Physiologists) chapter 13 pp 630-75
[31] Schwald W, Concin R and Bonn G 1985 Analysis of oligomeric and monomeric carbohydrates from hydrothermal degradation of cotton-waste materials using HPLC and GPC *Chromatographia* **20**(1) 35-40
[32] Garrote G, Dominguez H and Parajó J C 1999. Mild autohydrolysis: an environmentally friendly technology for xylooligosaccharide production from wood *J. Chem. Technol. Biotechnol.* **74** 1101-9
[33] Mittal A, Chatterjee S G, Scott G M and Amidon T E 2009 Modeling xylan solubilization during autohydrolysis of sugar maple and aspen wood chips: reaction kinetics and mass transfer *Chem. Eng. Sci.* **64** 3031-41
[34] Jacobsen S E and Wyman C E 2000 Cellulose and hemicellulose hydrolysis models for application to current and novel pretreatment processes *Appl. Biochem. Biotechnol.* **84-86** 81-96
[35] Lloyd T and Wyman C E 2003 Application of a depolymerization model for predicting thermochemical hydrolysis of hemicellulose *Appl. Biochem. Biotechnol.* **105-108** 53-67