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Evaluation of the Effects of Milling Time on the Physical Quality of Sarawak's Mamut Rice Traditional Variety

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Most consumers prefer white or well milled rice because of its superior taste. However, the increase in awareness on the consumption of nutritious foods such as brown rice or slightly milled rice justifies the need to study the milling quality especially of the specialty rice varieties. In this research, Mamut rice was selected because it has been identified by Department of Agriculture Sarawak to be promoted as a potential specialty rice variety for its superior characteristics having black pigment and aromatic traits. The physical quality evaluation such as the degree of milling (DOM), optical (whiteness, transparency) and colour (brightness, a* and b*) were discussed as one of the important quality parameters for this rice. Mamut rice was milled for 5 to 180 seconds at a-5 second interval using a laboratory abrasive polisher. Transparency and whiteness of the rice milled to different degrees of milling were measured using a laboratory milling machine while the brightness values (L*), a* values and b* values were determined using a laboratory colorimeter meter. The results of this study showed that the Whiteness, Transparency and Brightness (colour L*) increased with DOM as bran containing pigments were removed during progressive milling process. As the DOM increased, the Whiteness, Transparency and Brightness values increased from 6.23 to 40.60, 0 to 0.94 and 35.84 to 71.11 respectively. The changes in the values can be described in four different phases. PCA and AHC analysis based on physical quality of Mamut rice including milling quality, optical and colour parameters showed that the milling time that represented the bran fraction of Mamut rice variety is estimated at 50 s.

Keywords: specialty rice; degree of milling; whiteness; transparency; brightness

I. INTRODUCTION

In the production of higher rice quality, there is protocol for rice processors to follow to optimally retain rice quality parameters such as milling properties, appearance, nutritional value, cooking and eating quality. Each parameter has a set of specific criteria for establishing the suitability of rice for different markets or consumers; one crucial parameter is the milling properties. Rice is mostly consumed as a whole kernel of white rice obtained from rice milling process where the husk, all or part of the bran and germ are removed from the rough rice. In rice processing, the husk is first removed from paddy through dehulling operation to produce brown rice, leaving the bran layer intact on the rice kernel. The subsequent polishing or milling operation removes the bran layer to produce different degree of white rice.

Rice processing is therefore a combination of several operations that convert paddy into well-milled white rice with little or no bran remaining on the endosperm - the rice form that mostly preferred by consumers for its superior cooking quality (Mohapatra & Bal, 2006; Roy *et al.*, 2008). Bran and germ, however, are well known to contain high levels of minerals, protein, vitamins and antioxidant. Therefore, removal of the bran from the brown rice to produce milled rice could also lead to the removal of its

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nutrients (Roy *et al*., 2008). The amount of bran removal from the brown rice kernel is known as degree of milling (DOM) and usually expressed as percent DOM.

Rice samples are milled to specified DOM with different technique of classification. U.S. Department of Agriculture (USDA) had established DOM grades by visual determination (Giler, 1994). The milled rice whose appearance that meet this minimum milling degree requirement is considered “well milled,” “reasonably well milled” or “undermilled” based on the Visual Reference Image (VRI) standards. On the other hand, Belsnio (1992), classified DOM based on the removed outer layer of brown rice kernels and categorised the milled rice in 4 classes of DOM; 3-4% (under milled), 5-6% (medium milled), 7-8% (fully milled) and 8% (over milled).

In the context of preventing nutrient losses during rice milling, it is therefore important to understand and determine the milling fractions in rice. The present of this rice constituents can be analysed in milling fractions obtained after multistep milling of brown rice. There are studies reported on the measurement of DOM and its effects on the nutritional properties (Shobana *et al*., 2011; Monks *et al*., 2013). In a study reported by Resurreccion, Juliano, & Tanaka (1979), 80% of the kernel proteins were traced in the starchy endosperm (DOM>12%) while minerals were richer in the outer bran layers. DOM also affects milling recovery, nutritional composition, rice appearance and influences consumer preferences (Omer 2013; Puri *et al*., 2014). The increase in the consumer awareness, especially on the daily dietary intake, has led to variation of rice types with different DOM produced and sold in the market. DOM is even more critical in pigmented rice as the antioxidants are mostly presence in the bran layer.

Many factors have been studied with respect to the effects of DOM on overall rice quality. The study is widely carried out throughout the world, probably attributed to these variations in consumer demand in certain markets. Different markets need different degrees of bran removal. As for an instance, partially milled rice with long grains and brown rice is preferred by Americans, whereas in India, they preferred well milled parboiled rice where most of its bran is removed (Roy *et al*., 2008). In Malaysia, the most popularly consumed rice is well milled white rice, while the least consumed types of rice are the specialty rice which includes the brown rice, boiled, herbs and other kinds of rice (Noorlidawati, 2015). However, the consumption of specialty white rice especially with aromatic and pigmented traits is expected to increase in the future as the society becomes more affluent and health conscious. The cultivation of such specialty rice of traditional variety has now been aggressively promoted particularly in Sarawak to enhance local supply, export potential and increase farmer’s income.

The traditional rice varieties in Sarawak are widely grown by regions with an estimated over 300 varieties present. Among these, several varieties such as Bario, Bajong and Biris have the potential to meet such rice quality traits. In addition to those varieties, Mamut rice is also planted in Bijat-Stumbin regions of Sarawak and it is classified as specialty rice due to aromatic and black coloured kernel (Lai *et al*., 2017). In order to meet consumers’ demand and the potential of international markets, it is therefore necessary to explore Mamut rice quality through processing techniques to retain the unique characteristics of Mamut rice variety. DOM affects the milled rice quality and it is important for rice processor to mill rice appropriately without affecting its nutrient content.

According to Puri *et al*. (2014), varying the milling degrees not only affect the nutritional composition but also influenced the appearance of rice kernel. Studies by Schramm (2006), Lamberts *et al*. (2007) and Mohapatra & Bal (2014) founds that the lightness, whiteness and transparency of different varieties increases with the increasing amount of bran removal. This is because bran appears darker in colour and therefore changes in the colour depend on the amount of bran removal. Determination of the appropriate DOM for each variety is beneficial as it is an important concept in the rice industry, since DOM known to affect rice milling quality such as head rice yield, processing characteristics and cooked rice (Siebenmorgen & Lanning, 2013). It is also vital for rice millers to mill rice to a suitable degree without adversely affecting the nutrient value.

However, there is a lack of such information associated with Mamut rice variety. This study was therefore undertaken to evaluate the effects of milling process on the bran removal and its correlation with changes in the kernel physical appearances.

II. MATERIALS AND METHODS

A. Sample Preparation

Mamut rice, aromatic and colour variety (acquire from Batang Lupar, Sarawak), was selected for this study. The paddy was cleaned of its impurities and dried manually in the field to about 13 - 14% moisture content expressed as a percentage of wet basis unless otherwise stated. The dried paddy samples were kept in a refrigerator maintained at -10°C prior to further processing and analysis at MARDI Rice Research Station in Bukit Raya, Pendang, Kedah.

B. Milling of Rice

For each milling time, a 135 g paddy sample was dehulled using a laboratory scale paddy dehulling machine (Satake Rice Testing Husker Type THU35B). The resultant of brown rice was polished for 5 to 180 s at 5 s interval to obtain different milling fractions using laboratory scale rice polisher (Satake Grain Testing Mill Model TM 05).

The polished rice was sieved to obtain Milled Rice (MR) by using Endecotts Laboratory Test Sieve (1.40 mm), Brewers Rice (BRW) and Rice Bran (BRN) by using The Pascall Engineering Co, Ltd Test Sieve (1.00 mm) and 1.6 mm rice processing sieve. MR, BRW and BRN were expressed as the mass percentage of the 135 g of paddy.

The MR samples obtained were placed on the grader (Satake Testing Rice Grader Type TRG 05A) to separate the Head Rice (HR) and Broken Rice (BR). Head rice and BR are expressed as the mass percentage of the 104 g of brown rice. A good quality paddy usually constitutes of 23% husk, 77% brown rice, 8% bran and germs, 1% brewers and 68% milled rice or total rice (Said & Ali, 2001).

Rice degree of milling (DOM) was determined by method as:

$$\text{Degree of Milling} = (\text{wt. of bran}/\text{wt. of brown rice}) \times 100 \quad (1)$$

C. Optical Measurements

Satake milling meter (Model MM1D, Satake Engineering Co., Ltd., Tokyo, Japan) was used to measure the optical characteristics of the milled rice for all samples where the reflected light measures the whiteness (W), while the transmittal light measured the transparency (T). The measurements generally range from 5.0 to 70.0% and 0.01 to 8.0% for W and T respectively. The two combination of W and T give a measurement of milling degree (MD), which range from 0 to 199.

D. Colour Measurement

The colour values after milling was determined by colorimeter (Konica Minolta Model CR-400). Head Rice (HR) samples for each DOM level was measured and expressed in values (L*, a* and b*). The L* value (luminosity) corresponds to the degree of brightness/lightness which is rated from 0 (black) to 100 (white). The a* value indicates the degree of redness with colour values ranging from –60 (green) to + 60 (red) while the b* value represents the degree of yellowness ranging from -60 (blueness), zero (gray) and +60 (yellowness).

E. Statistical Analysis

All data are reported as mean values from three replications. The statistical analyses of data including the correlation, Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (AHC) were performed using XLSTAT (Addinsoft, New York, NY, USA) statistical software package.

III. RESULTS AND DISCUSSION

A. Effect of Milling Time on Milling Quality of Mamut Rice

Figure 1 shows the plots of milled rice (MR), head rice (HR), broken rice (BR), rice bran (BRN) and brewers rice (BRW) against milling time that can be equated with DOM. The trends show that MR and HR, the two crucial characteristics affecting rice milling quality, were negatively correlated with milling time. The rate of MR and HR decrease with milling time were almost constant with milling time as shown by an almost linear relationship. The longer the milling time therefore, the lower the rice milling quality.

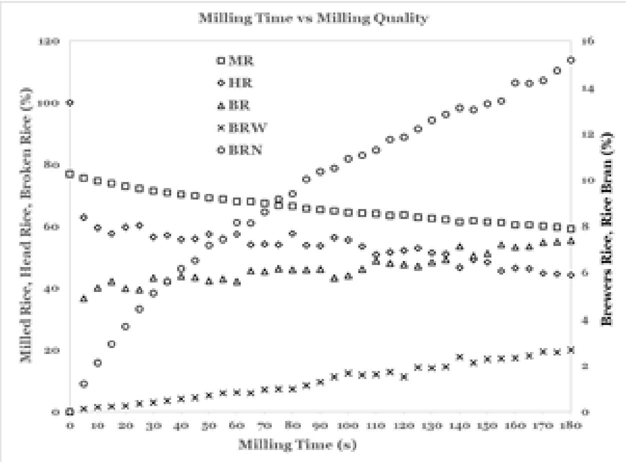

Figure 1. Effect of milling time on rice milling quality of Mamut rice

The BR, BRN and BRW on the other hand, were positively correlated with milling time, of which the BR and BRW were increased almost linearly with increase in milling time. The rate of BRN and BRW removal were therefore almost constant as milling time is increased. The increase in the amount BRN removal with milling time on the other hand, showed curvilinear relationship in the first 50 to 60 s of milling time, but the amount removed was almost linear thereafter. The first 50 to 60 s of milling time exhibited that the BRN was removed at an increasing rate, and the rate of removal was higher than that at linear section. Others studies also found similar correlationships where by increasing milling time from 30 to 90s, significantly increased the percentage of BR and BRN (Abd El Salam, 2017).

B. Effect of Milling Time on Optical Characteristics of Mamut Rice

Figure 2 shows the plot of whiteness (W), transparency (T) and milling degree (MD) of Mamut rice variety against milling time. Whiteness, T and MD values of the rice increased with increase in the milling time. The general trend in the changes indicated that W values did not increased until at least 25 s of milling time; indicating minimal or no removal of bran during the first 25 s. The W then showed a slower increment until 40 s of milling time (whiteness value 12.13%). However, it was after 50 s of milling time and onwards that the W value started to increase at higher rate; there was a clear break in the changes in the W value from about 14.17% to 16.27% at a milling time of 50-55 s. Based on the changes in the W value, it can be inferred that the bran fraction of Mamut rice variety is completely removed after about 50 s milling time. The W value was then observed to continue to increase until its final value of 42.1% at 180 s milling time. As milling time was increased, more bran is slowly removed from the surface of the rice kernel and the kernel becomes whiter. As the result, the whiteness value can be distinctively recorded by the whiteness meter. The kernel whiteness increment can therefore be correlated with increase in bran removal.

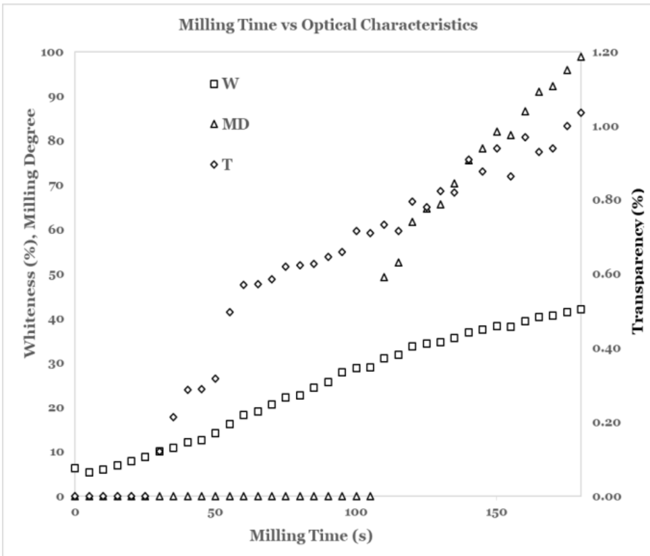

Figure 2. Effect of milling time on optical characteristics of Mamut rice

The relationship between percentages of T values of the rice kernel with milling time indicated T value increased from 0 to 1.04% as the milling time was increased from 0 to 180s. Interestingly, during the first 25 s of milling time, the T values were zero as it cannot be detected by the instrument. The T value can only be detected after about 30 s of milling time; where the value was recorded as 0.12%.

Between about 50-55 s of milling time, the T value showed a mark increase from 0.32% to 0.50%. Based on T value, the above range of milling time could be the limit for the bran fraction for Mamut rice variety. The T value then increased gradually until 1.04% at 180 s of milling time.

In this study, however MD only can be detected after 105 s. After 110 s milling time onwards, its value increases gradually until its final value at 180 s of milling time. The recorded values of MD were 49.33 to 99.00 from milling time of 110 to 180 s.

The W and T values in Mamut rice variety are consistent with values reported in the literature for pigmented rice. Schramm *et al.* (2012) reported that the whiteness and transparency values of purple rice variety were three to four times less than non-pigmented rice. In their study, the whiteness value for pigmented rice was highest (14.9%) at 40 s of milling time. However, the transparency values were found to be not significantly different at the shortest milling time. At longer milling time, transparency value for the purple rice variety was recorded to be closed to 1%. As comparison, the whiteness and transparency values for non-pigmented rice were reported to be between 40% to 60% (Reid *et al.*, 1998) and 3% to 4% (Pan *et al.*, 2005) respectively. Other study by Sison *et al.* (2006) also concluded that whiteness, transparency and milling degree increases with milling time. This two variables, W and T give an indicator for the appearance while MD is an indicator of the percentage of bran removal.

The optical measurements can provide an indication of the number of outer layers of rice which have been removed in milling. A high MD, defined as highly polished and whitened rice that have no traces of bran - which is preferred by Asian, is used commercially for low amylose white rice (Andrews, 1992). In the study, the MD can only be recorded by extending the milling time until 105 s, whereby about 14% of rice removed (DOM).

There are instances where well milled rice would contains some parts of the lengthwise streaks of the bran layers on the surface with kernels slightly grey in colour (Belsnio, 1992; Salman, 2010), that further extension of milling will yield the required values of milling degree. That similar condition can be detected on Mamut rice as shown in Figure 2, where an extension of milling until 105 s (14% DOM) removed all the bran layers from the kernels. This should be the limit for 2nd phase of rice fraction (outer endosperm) classified by Lamberts *et al.* (2007) but at different DOM (9-15%).

C. Effect of DOM on Colour Parameters of Mamut Rice

The International Commission of Illumination (CIE) Lab (CIE, 2014) with L* a* b* colour space technique was adopted and the colour were measured in the study. L* indicates the lightness or brightness, while a* and b* reflect the colour intensity.

Figure 3 shows the relationship of the colour parameters of the Mamut rice with different milling time. The L* values or brightness for Mamut rice increased from 35.84 to 73.51 as milling time was increased. Similar break in the L* value (from L values 48.3 to 50.00) can also be observed at 50-55 s milling time (DOM of 9-10%), inferring the milling time for the bran fraction of Mamut rice variety. Lamberts *et al.* (2007) reported similar trend but with a lower milling time of 15 s (equivalent of 9% DOM), beyond which the endosperm is exposed. The brightness (L*) increased until at 14% DOM (equivalent to 105 s of milling time). Further milling did not affect the brightness value very much. Based on Lamberts *et al.* (2007) findings, the fraction corresponding to 0-9% and 9-15% DOM were considered as bran and outer endosperm respectively.

Similarly, the trend for redness (a*) and yellowness (b*) are found to decrease until 14% DOM. The a* value was then detected below zero as it reaches core endosperm. While the b* value remained constant in middle and core endosperm. This results can infer that pigments are abundant in the bran and outer endosperm as also concluded in Lamberts *et al.* (2007) findings.

Those three measured colour parameters were associated with bran removal rate and depend on severity of milling. An increase in the DOM, increased the brightness (L*) while the color intensity (a* and b*) are decreased (Lamberts *et al.*, 2007).

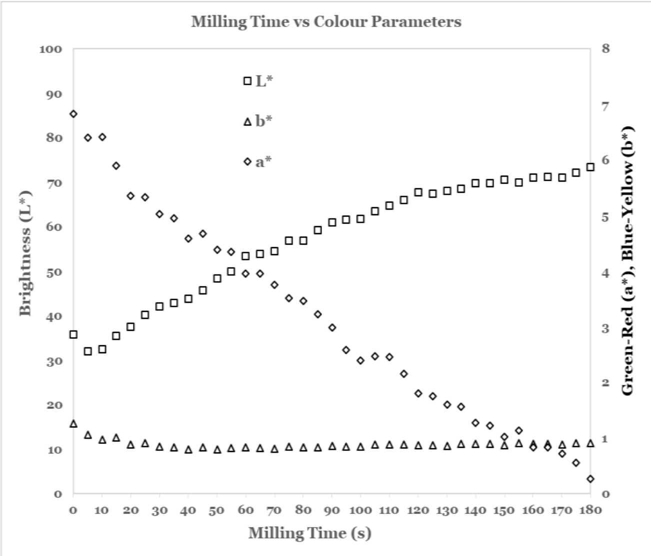

Figure 3. Effect of milling time on colour parameters of Mamut rice

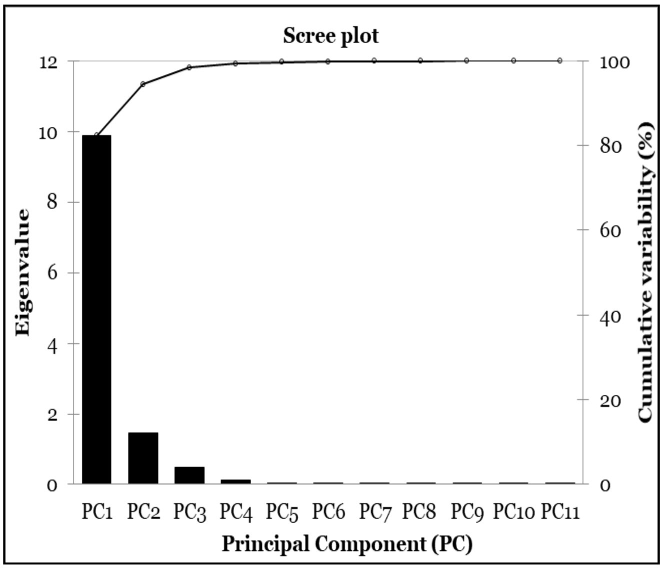

Figure 4. Scree plot showing Eigen values and percentage of cumulative variability

D. Principal Component Analysis (PCA)

To further understand the relationship between milling time and physical quality variables, multivariate analysis, PCA was performed. The result of PCA explained the most important physical quality factors contributed to Mamut rice quality at different milling time.

In the current study, PCA was conducted for 12 physical quality variables as discussed in earlier section which revealed the principal discriminatory characteristics such as milling quality, optical and colour parameters for this Mamut variety. This PCA model as depicted as a Scree plot (Figure 4), showed the percentage of variation associated with each principal component while the Bi-plot (Figure 5), showed the physical quality variables structure of first two components under varying milling time. Samples closed to each other on the plot indicated similar properties. The PCA detected two PCs (Figure 4): PC1 and PC2 accounted for 82.32% with Eigen value 9.879 and 12.10% with Eigen value 1.452, respectively, making 94.43% for the total variance accounted in this PCA model (Table 1). From the graph, it was clear that the maximum variation was observed in PC1.

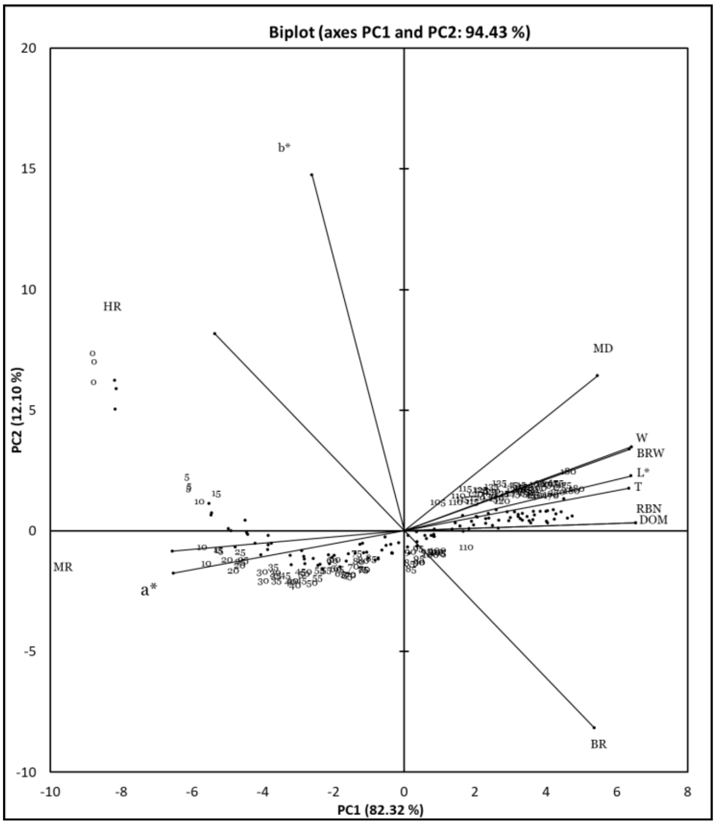

Figure 5. Bi-plot showing the distribution and grouping of 111 rice samples across first two components based on PCA

Table 1. Eigenvalue, factor loading and contribution of the first two principal component to factors affecting rice quality

Variable	**Principal**	
	PC1	**PC2**
Eigenvalue	9.879	1.452
Variance (%)	82.32	12.10
Cumulative (%)	82.32	94.43
Milled Rice	-0.995	-0.049
Head Rice	-0.812	0.475
Broken Rice	0.817	-0.476
Brewer Rice	0.967	0.197
Rice Bran	0.993	0.019
Degree of Milling	0.993	0.019
Whiteness	0.976	0.203
Transparency	0.965	0.103
Milling Degree	0.829	0.374
Colour (L*)	0.973	0.133
Colour (a*)	-0.990	-0.102
Colour (b*)	-0.396	0.859

From Figure 5 and Table 1, b* values are separately positioned from the samples, indicating that it was not significant, where the factor loading was also low, -0.396. While BRN as well as Degree of Milling (DOM), BRW, W, L* values and T were grouped together and have positive loading (which close to 1), indicating that these parameters had positive correlation among themselves and strongly influenced the PC1, while MR, HR and a* values has negative loading values, indicating the negative correlation.

The correlation analysis showed that BRW, W, T, L* values were positively correlated with DOM. The computed Pearson correlation coefficients on these variables were 0.956, 0.978, 0.978 and 0.987 respectively. The MR and a* values were negatively correlated with DOM with a correlation coefficient of -0.999 and -0.990. The larger absolute values of these coefficients indicated the stronger relationship between the variables. Positive correlation coefficients of the BRW, W, T and L* values indicated that the parameters increased with increasing DOM. Conversely, the negative correlation coefficient of the MR and a* values showed that they decreased as DOM increased. The decrease in MR is a result of removal of bran layer and the increase of BR as the milling time increases.

Physical quality with similar information (correlated) were clustered together, and the further away they were from the origin, the stronger their contribution to PCA model. From the bi-plot (Figure 5), rice samples with different milling time were separated according to its physical quality. Figure 5 suggested that the BRW, W, T, L* were highly expressed in longer milling time. In contrast, MR and a* values were expressed in short milling time. This could indicate the limit for outer endosperm whereby the bran layers have totally removed from the rice kernels. As a* values is highly content in the bran, in the longer milling time, the a* values are less significant.

E. Agglomerative Hierarchical Clustering (AHC)

The obtained PCA result was good for rice fraction determination and was more clearly classified or differentiated according to milling time using agglomerative hierarchical clustering (AHC) as presented in Figure 6. Three clusters of milling time of Mamut rice samples were defined based on its physical quality. The cluster 1 was classified for 0-50 s of milling time. In this cluster, shorter milling time below 50 s, corresponds to its physical quality that explain the limit for bran fraction as discussed in previous section. The cluster 2 consisted of 11 level of milling time, 55-105 s, while the other 15 level of milling time, 110-180 were grouped together in cluster 3.

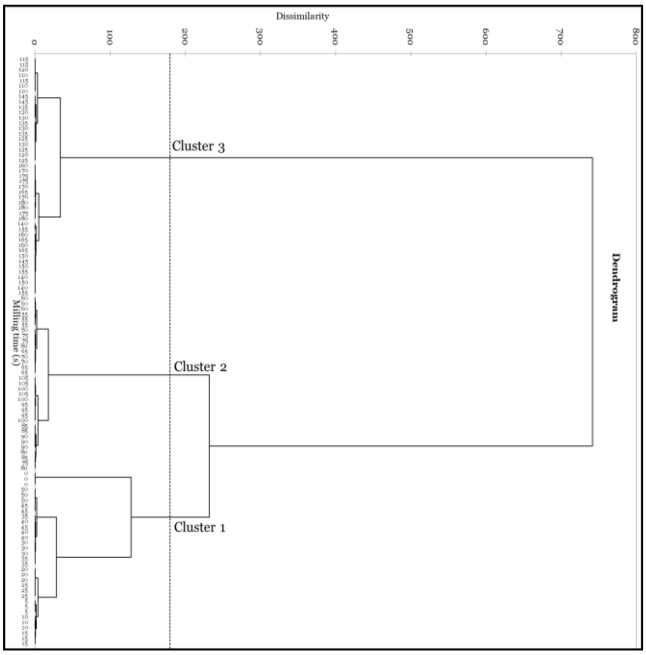

Figure 6. Dendogram AHC of Mamut rice variety based on physical quality

F. *Relationship between Degree of Milling and Milling Time*

The Mamut brown rice that was polished from 0 to 180 s at a 5 s interval yielded various DOM, ranging from 0 to 19.70%. The DOM of the Mamut rice is presented as a function of the milling time. The milling kinetics, represented by DOM as a function of time, is presented in Figure 7. As the milling time increased, the DOM increased with peculiar trend in the slope. This general observation is coherent with the findings of Lamberts *et al.* (2007) who conducted DOM study on long grain of Puntal rice variety.

The relationship in DOM against milling time for the Mamut rice variety (Fig 7) was further described in four different phases, according to the correlation, PCA and AHC of physical quality analysis. The Phase 1 was identified at milling time of between 0-50 s, while Phase 2 at 55-105 s, Phase 3 at 110-160 s and Phase 4 at 165-180 s. It can be observed that the initial slope (Phase 1) is the highest during the first 50 s (an equivalent to 9% of DOM), where the rate of change of bran removal was calculated to be ranging from 0.91 - 12.25% (0.194 to 0.327 g bran/s of removal rate). The highest percentage of DOM value in the first phase is reported to be attributed to the removal of the germs during milling. According to the work of Lamberts *et al.* (2007), the slope of DOM versus milling time was also found to increase during the first phase, but with lower milling time (0-15 s or an equivalent of 9% DOM). Similar trend was observed by Mohapatra and Bal (2014) but in a slightly longer milling time (30 s).

The Mamut rice milling kinetic was then followed with a slower rate of change in DOM (Phase 2) until 105 s (an equivalent of 15% DOM), where the rate of change of bran removal ranged from 0.63 – 6.25% (0.166 to 0.181 g bran/s). The rate of change of DOM then continue to increase slowly until 160 s, where the rate of change of bran removal ranged from 0.61 – 4.05% (0.139 to 0.126 g bran/s). Then the rate of change of DOM plateaued until 180 s (Phase 4) with bran removal rate fluctuating between 0.113 to 0.116 g of bran/s.

Such trend in the rates of bran removal demonstrated by rice during milling is postulated to be due to the significant difference in hardness between bran and endosperm (Lambert *et al.*, 2007). The hardness of the bran increased from outer to inner layers, whereas the hardness of the different endosperm fractions was similar. This first phase (Figure 7) is generally associated with the rice fraction. The trend in the DOM as reflected in Phase 2, 3 and 4 can be attributed to the kernel hardness as reported by Mohapatra and Bal (2004) where there is higher and consistent hardness in the core as compared to the outer layers.

Based on the analysis, the bran fraction for this Mamut rice variety can be estimated to be within the 50 s of milling time (an equivalent of 9% DOM). After 50 s, the rice fraction can then be described as three different fraction of endosperm namely Outer endosperm (55-105 s), Middle endosperm (110-160 s) and Core endosperm fraction (165-180 s). It should be noted that the core endosperm was determined based on starting zero a* values that in line with previous studies by Lamberts *et al.* (2007) and Rodriguez *et al.*, (2016).

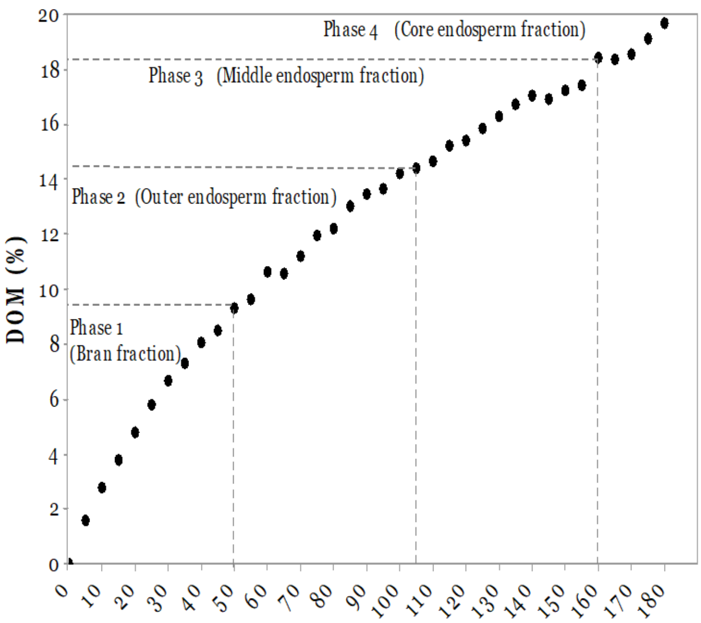

Figure 7. DOM as a function of Milling time of Mamut rice

IV. CONCLUSION

As the bran layer of Mamut rice variety is progressively removed during milling, its physical quality parameters such as the rate of bran removal, total rice, head rice, broken rice, brewer rice, transparency, whiteness, and brightness and colour intensity changes in some fashions. At 45-65 s of milling time, about 7-8% of bran removed from brown rice. This 7-8% DOM can be categorized as fully milled or well milled for Mamut rice. The 9-10% of DOM of Mamut rice is represented by 50-55 s. Normally well-milled rice has 10% DOM during whitening. The analysis indicated that DOM 9% is the limit for bran fraction and was in line with earlier work by Lamberts *et al.* (2007) who classified DOM from 0-9% as bran fraction. In this study, at 50 s milling time or an equivalent of 9% DOM, was determined as the limit for bran fraction and can be categorized as well milled for Mamut rice. Establishing bran fraction in any newly introduced rice varieties such as Mamut rice is important as the consumers expected the highest retention of nutrients that are associated with the bran layer such as minerals, fats, fibres, vitamins and the critical antioxidants. On the other hand, further milling beyond 50 s of milling time will then begin the removal of the endosperm layer, which can also lead carbohydrate and protein losses.

V. ACKNOWLEDGEMENTS

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