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Related Fracture Resistance with Moisture Content in Different Grain Orientation of Paddy Grain

Renny Eka Putri[1,3] Azmi Yahya[1] Nor Maria Adam[2] Samsuzana Abdul Aziz[1]
1.Department of Biological and Agricultural Engineering, Faculty Engineering, University Putra Malaysia, 43400 Sedang, Selangor D. E., Malaysia
2.Department of Mechanical Engineering, Faculty Engineering, University Putra Malaysia, 43400 Sedang, Selangor D. E., Malaysia
3.Department of Agricultural Engineering, Faculty of Agricultural Technology, University Andalas, West Sumatera, Indonesia

Abstract
The relationship between different levels of moisture content on rupture force at different grain orientation was determined for paddy grain. The rupture force is the minimum force required to break the sample. An Instron testing machine was used to perform a compression test on paddy grain. The result showed that strong relationship between rupture forces of the grain and moisture content for both orientations. The rupture force decreases 38.5822 N to 11.7777 N as increasing moisture content from 11.3% to 29% in vertical orientations (Y-Y). The results also show that in horizontal (X-X) orientation, rupture force decrease from 150.8382 N to 90.1287 N as increasing moisture content from 10% to 29%. It was found that the rupture force values of paddy at the X-X load orientation were higher than those at the Y-Y load orientation for the entire range of moisture content. Implications of the results will be important for millers and end users of paddy industry for milling and post-milling processes.
Keywords: Paddy grain, fracture resistance, moisture content and grain orientation.

1. Introduction

Currently, percentage of whole and unbroken rice kernels was became an important quality criterion for rice industry. The economic value of the drayed product is strongly dependent on the percentage of unbroken kernels (Siebenmorgen, 1994). Especially in grinding and milling process in rice industry, the mechanical properties of grain are important for designing machines for these tasks (Kang et al. 1995 and Yücel et al. 2009). These properties are also important in order to design machines for harvesting, cleaning, separating, and processing. Rupture force is one of the most significant mechanical properties of a paddy grain. Rupture force is the minimum force needed to rupture the individual grain (Sirisomboon et al. 2007). If the compression exceeds the rupture strength of the material, it will lead to cracks or breakage.

There have been several studies in the literature reporting in mechanical properties of several grains. The effect of deformation rate and moisture content on the mechanical properties of rice grains were carried out by Kamst, et al (2002). They identifies that at moisture contents of 8.87% (w.b.) and lower, the values of Young's modulus and tensile and compressive strength were not significantly different from each other, while at higher moisture contents the properties declined with moisture content. Furthermore, several studies have been conducted that consider the moisture content dependent on physical and mechanical properties of wheat, such as those by Dobraszczyk et al. (2002), Tabatabaeefar (2003), Karimi et al. (2009), Kalkan and Kara (2011), and Babic et al. (2011). However, Tabatabaeefar (2003) and Karimi et al. (2009) did not investigate the mechanical properties of wheat grains. Delwiche (1993) measured the hardness of individual wheat kernels using near infrared transmittance. Gupta and Das (2000) also provided that the compressive force needed to initiate rupture of both sunflower seed hulls and kernels decreased with an increase in moisture content, while the energy absorbed at rupture increased. Altuntaş and Yıldız (2007) have demonstrated that the rupture energy of the faba bean grain generally increased with an increase in moisture content, while the rupture energy increased. In addition, Dobraszczyk et al. (2002) studied the fracture properties of endosperm machined from individual wheat kernels from several wheat varieties. The mechanical behavior of different wheat varieties was determined by Güner and Dursun (2003) using compression loading between 2 parallel plates. They reported rupture force decreased and rupture energy increased as wheat moisture content increased. Similarly, Kalkan (2011) found that while the rupture force values of wheat grains decreased as the moisture content increased the deformation at rupture point, energy absorbed, and grain hardness did not show any regular variation with the moisture content.
Some mechanical engineering properties of locust bean seed were investigated by Ogunjimi et al. (2002), who concluded that the seed orientation that gave the least resistance to cracking was along the thickness. The cracking force found in loading along the thickness lay between 154 and 204 N. Loading on the vertical axis gave the highest resistance to cracking. In their study, Işik and Ünal (2007) summarized that the shelling resistance of white speckled red kidney bean grain decreased from 98.26 N to 53.67 N as the moisture content increased. Additionally, a similar study was done by Altuntaş and Karadag (2006) in that the mechanical

properties of sainfoin, grasspea, and bitter vetch seeds were determined in terms of the average rupture force, specific deformation and rupture energy along X-, Y- and Z-axes. Limited research has been conducted on the mechanical properties and fracture force of paddy grain. Objectives were to determine rupture force paddy grain by examining the effect of moisture content and grain orientation.*1.1*

2. Material and Methods

Paddy varieties MR 220 CL2 was obtained from the rice cultivation in Tanjung Karang Selangor Malaysia. MR 220 CL2 is one of the paddy seed produced by Malaysian Agricultural Research and Development Institute (MARDI). To determine the average size of the paddy grain, a sample of hundred seeds was randomly selected. The three linear dimensions of the seeds, namely length (L), width (W) and thickness (T) were carefully measured using micrometer reading to 0.01 mm. The geometric mean diameter (GMD) and sphericity ratio were computed using the following equations (Mohsenin, 1986).

GMD = (L*W*T)1/3 and Sphericity = GMD/L

A hundred paddy grains randomly selected for determining the geometric mean diameter and spericity. It was used as a parameter for physical properties of paddy in experiment. Then, the mechanical properties of paddy grain were determined in terms of average rupture force. Quasi-static compression tests were performed using a proprietary tension/compression testing machine (Instron Universal Testing Machine). The load cell connected to the upper plate of the device converted the force applied to the single grain during compression into electronic signals, and then transferred the signals to a computer through a data acquisition board, recording the data on the computer for offline analyses. Loading was applied to each grain in 2 main directions, namely X-X and Y-Y load orientations (Figure 1). The experiments were also conducted at loading rates of 3 mm per min. The fixed loading speed of the device and elapsed time were used to determine the deformation that occurred during loading up to the rupture point for each individual grain (Altuntaş and Yıldız, 2007). The rupture force was measured directly by the loading device. A single grain was positioned on the lower plate of the device, and the lower plate was then moved upward with a fixed speed of 3 mm per min, compressing the grain between the 2 parallel plates until it fractured (ASAE 2005).

In order to determine the effect of moisture content against rupture force, the grain will condition in deferent moisture content with range of moisture content 10-30% in wet basis. The initial moisture content of the sample was determined by using G-7 Grain Moisture Meter. The G-7 Grain Moisture Meter from Delmhorst having nominal range of 9 to 30% moisture content. To vary the moisture content, the paddy must undergo drying process. Drying process was done in the moisture analyzer M50. Moisture analyzer M50 is equipment that able to determine moisture content inside paddy. This equipment was set up for standard drying process that is 105^{o}C. On the moisture analyzer screen were displaying the operation temperature, drying time, drying rate, and moisture content measurement. The relationship between rupture force with the moisture content are the objective of the research, so to monitor the changing of rupture force of the paddy with the moisture content of paddy, the drying process must be done by different time of drying process. The drying processes for this research were done in 0 until 10 minutes inside the moisture analyzer. The different time of drying process is used to get vary of moisture content with range from 10 to 30%. After drying process, paddy will be put in silica gel desiccant for stabilization temperature inside paddy before rupture test. Paddy will put in the dedicator for one hour. Finally, after the time achieve, twenty five grains were randomly selected to determine the rupture force using Instron machine. The experiment done with different moisture content range 10-30% and the average values of all the twenty five tests will be reported for each vertical and horizontal orientation. A statistical analysis was performed on the experimental data obtained using Statistical Analysis System (SAS) software.

3. Result and Discussion

Descriptive statistic of size of paddy grain was used in the experiment showed in Table 1. Geometric Mean Diameter (GMD) of the paddy grain is approximately 3.7759 mm with the standard deviation 0.2883 mm. The paddy grains ware used in this experiment almost similar. It showed the coefficient of variance less than 15%, indicated low variability of data distribution. The effect of moisture content and grain orientation on fracture resistance of paddy rice grain was determined. And the spericity of the paddy grains is 0.3466 with the standard deviation 0.0279. From this data we can see that the Paddy varieties MR 220 CL2 is not around shape, due to the spericity value less than one.

The force required for initiating the grain rupture at different moisture contents and grain orientations at loading rates of 3 mm per min is shown in Figure 2 and 3. As a show in figure that the rupture force decrease from 38.5822 N to 11.7777 N as a increasing moisture content from 11.3% to 29% in vertical orientations, it also happened in horizontal orientation rupture force decrease from 150,8382 N to 90.1287 N as a increasing moisture content from 10% to 29%. The variance analysis of the data indicated that the moisture content and grain orientation exerted a significant effect on the rupture force. The results showed that the rupture force of paddy grain decreased by increasing the moisture content for both grain orientation (X-X and Y-Y load orientations). This finding highlights that the value of grain rupture force at the horizontal orientation was higher than the vertical orientation. This value indicated how easily the material can be broken. This may be due to the fact that at higher moisture content the grain became softer and required less force.

Regression analysis of the data showed that rupture force was linearly correlated with moisture content for X-X and Y-Y orientation with R^2 = 0.867 and 0.825, respectively. Figure 2 and 3 also show the linear regression of rupture force and moisture content was highly significant. The present finding also support Zareiforoush (2010) study which concluded that mechanical properties of two paddy varieties under quasit-static compressive loading. The result showed for Alikazemi variety, as the loading rate increased from 5 to 10 mm/min, the force required for initiating the grains rupture decreased from 125.69 to 117.38 N and 33.51 to 29.94 N, respectively, at horizontal and vertical orientation. And for Hashemi variety, the grains rupture force decreased from 109.96 to 88.33 N and 25.39 to 21.68 N, respectively, at horizontal and vertical orientations with an increase in loading rate from 5 to 10 mm/min.

Rupture force decreased with an increase in seed moisture content for both grain orientation (X-X and Y-Y orientation). The relationship between rupture force and moisture content has been widely investigated. As given in figure 3 in horizontal orientation, rupture force was 38.5822 N at 11.3% moisture. This is significantly more than the force required to initiate seed rupture at 29% moisture (around 3.27 times). In figure 4 (vertical orientation), also showed rupture force was 150.8382 N at10% moisture. And significantly more than force required to initiate seed rupture at 29% moisture (around 1.67 times). This may be due to the fact that at higher moisture content, the seed became softer and required less force. This conclusion was consistent with the findings of Konak et al. (2002), who reported the highest rupture force of chick pea seeds was obtained as 210 N with a moisture content of 5.2% (dry basis). It was also stated that the seeds became more sensitive to cracking at higher moisture content; hence, they required less force to rupture. Altuntas and Yildiz (2007) also conducted a research to study the effect of moisture content on some physical and mechanical properties of faba bean grains (Vicia faba L.) grains and reported that as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 to 185.10 N; 242.2 to 205.56 N and 551.43 to 548.75 N for X-, Y-, and Z-axes, respectively.

Figure 4 and 5 shows a typical force-deformation curve for a paddy in compressing. As shown in the figure, deformation is linearly related to applied load up to the break point. The break point was indicated by a significant drop in applied force. Therefore, the compressing force at break was considered as the maximum compressing force, or breaking force. Considering the values presented in figure 4 and 5, the paddy grain were more flexible in the horizontal loading orientation and the rupture under vertical loading direction requires less rupture force than that under horizontal loading. The finding provides evidence that paddy grain easily to broken in vertical orientation than horizontal orientation. This is possibly due to the fact that under vertical loading, smaller contact area of the grain with the compressing plates results in the expansion of high stress in the paddy grain.

4. Conclusion

In conclusion, the rupture force has strong relationship with moisture content for both grain orientations. Rupture force decreases 38.5822 N to 11.7777 N as increasing moisture content from 11.3% to 29% in vertical orientations (Y-Y). The same trend also happened in horizontal (X-X) orientation, rupture force decrease from 150.8382 N to 90.1287 N as increasing moisture content from 10% to 29%. The rupture force values of paddy at the X-X load orientation were higher than those at the Y-Y load orientation for the entire range of moisture content. In other words, the lower the moisture content, the harder the grain. This finding may be important for millers and end users of paddy for milling and post-milling processes.

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Table 1. Statistic analysis Geometric Mean Diameter (GMD) paddy grain

Parameter	GMD	SPHERICITY
Mean	3.775865	0.346674
Median	3.75044	0.342664
Standard Deviation	0.288356	0.027881
Range	2.897133	0.264958
Minimum	3.500326	0.31822
Maximum	6.39746	0.583178
Coefficient of variance (%)	7.63	8.04
Count	100	100

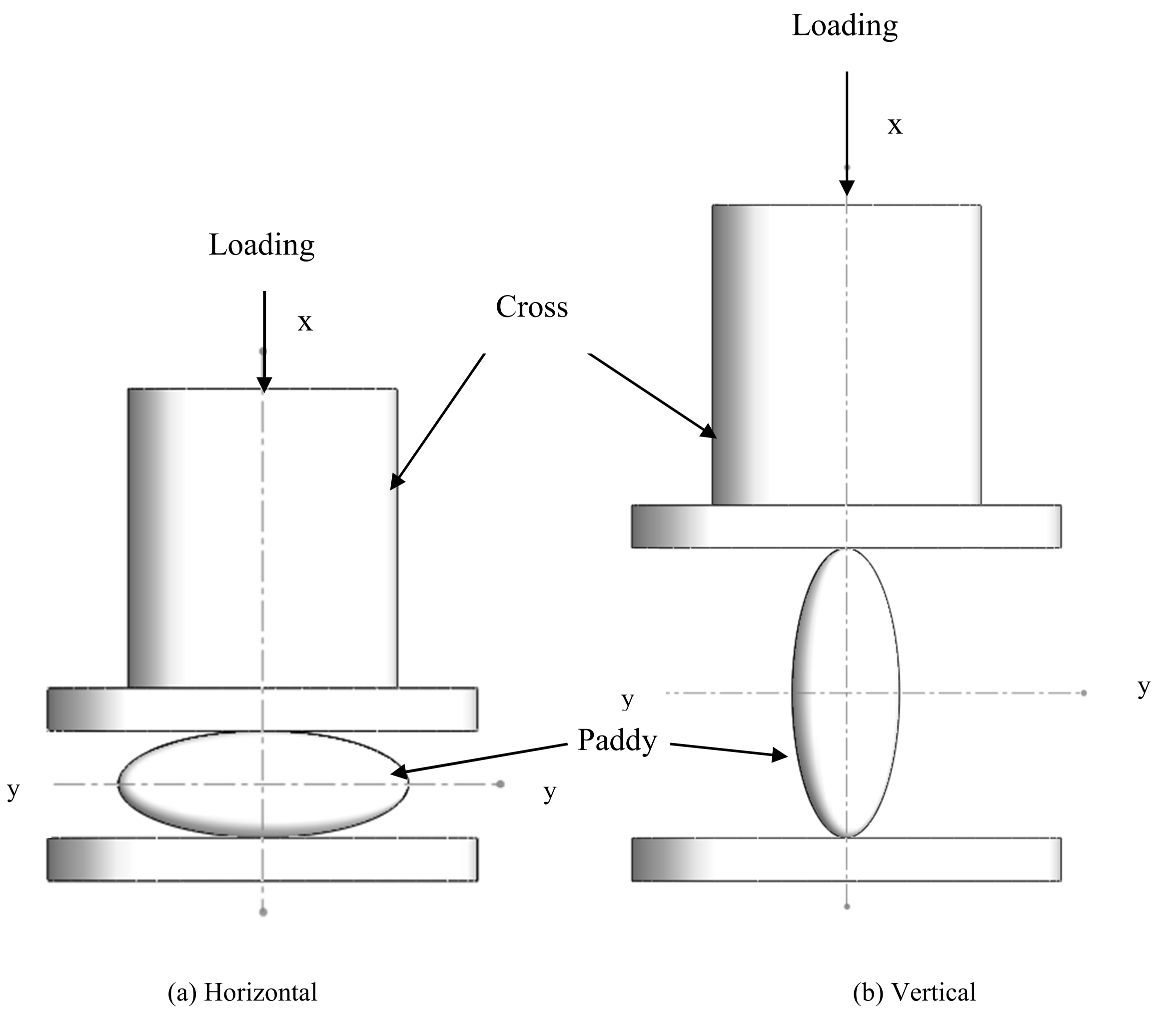

Figure 1. Orientation of paddy grain under compressive loading

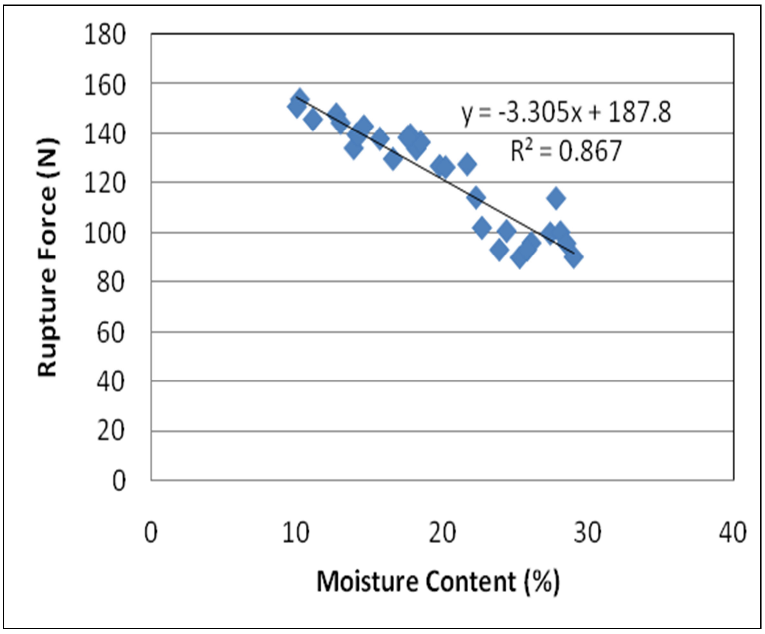

Figure 2. Effect of moisture content on rapture force for paddy in horizontal orientations (X-X orientation)

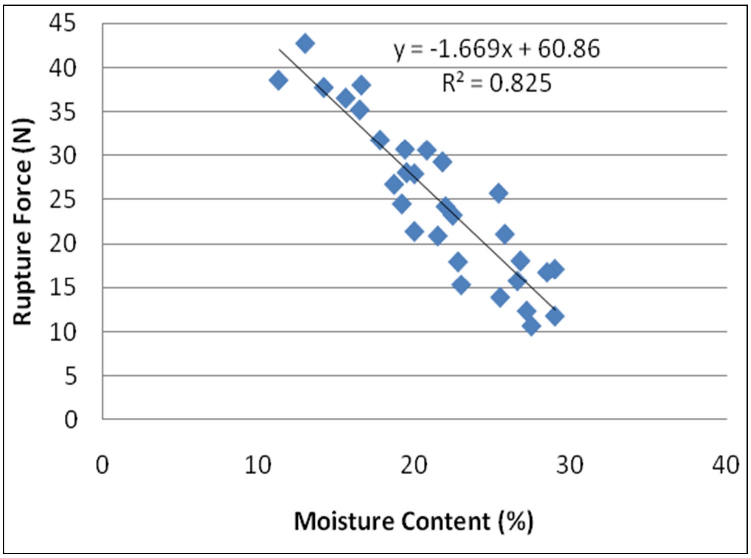

Figure 3. Effect of moisture content on rapture force for paddy in vertical orientations (Y-Y orientation)

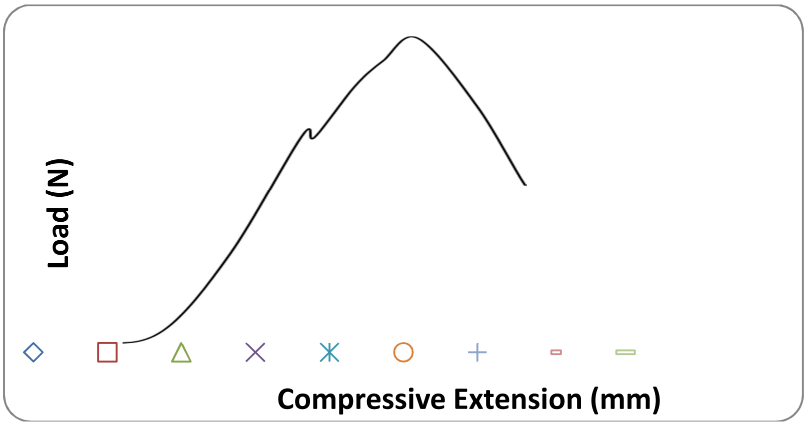

Figure 4. The force versus displacement curve for paddy in horizontal orientations (X-X orientation).

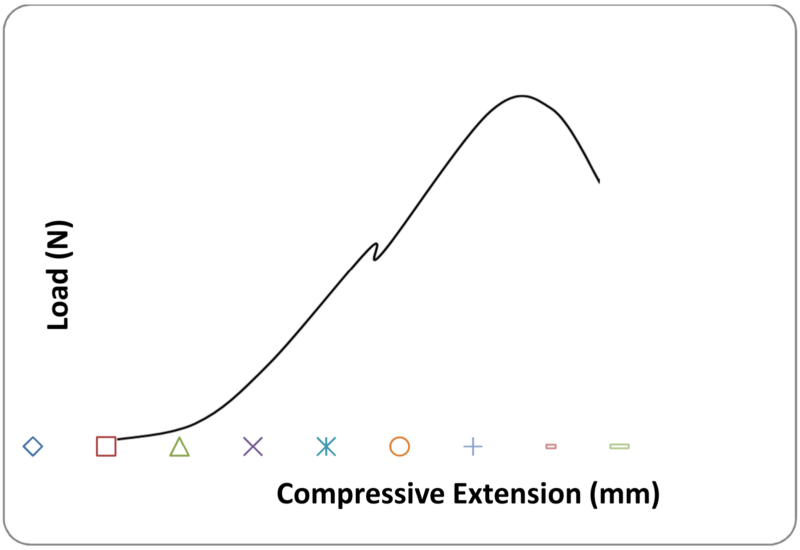

Figure 5. The force versus displacement curve for paddy in vertical orientations (Y-Y orientation).