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Effects of Moisture Content and Grain Type on Mechanical Properties of White Rice: Literature review and Experiment

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ABSTRACTS

The mechanical properties of agricultural grains are required in the design of agricultural processes and machinery. These properties are influenced by moisture content and grain type. This study aimed to determine the effect of moisture content and grain type on the mechanical properties of white rice. There are three different types of white rice, namely short-bold (Koshihikari), long-medium (IR 64), and very long-slender (Basmati) grains within three levels of moisture content of 9%, 14%, and 19% were used as the samples in the experiment. The experiment was designed into Completely Randomized Design, factorial 3 x 3. The dimension, internal friction angle, and rupture force of the grain samples were respectively measured using a digital calliper, direct shear cell apparatus, and compression test apparatus. It could be concluded that moisture content, grain type, and the interaction of these two factors significantly affected almost all parameters of the mechanical properties of white rice. Most of the relationships between the parameters of mechanical properties and moisture content could be expressed as linear equations.

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1. INTRODUCTION

Grain is known as a staple food for the majority of the world's population, which is why it is cultivated all over the world and covers the largest cultivated land. One of them is rice, which is a staple food, especially in Asian countries (Segal & Minh, 2019; Shakri *et al*., 2021; Nueva *et al*., 2022). It is estimated around 90% of rice is consumed in Asia (Bandumula, 2017). Similar statements were also expressed by other researchers (Muthayya *et al*., 2014; Anthony *et al*., 2016; Fukagawa & Ziska, 2019; and Lin *et al*., 2022). Productivity, quality, availability, and sustainability must be ensured year-round to feed nearly half of the world's population.

The projected world milled (white) rice production in 2022/2023 will reach 512.44 million metric tons and during that period, rice production in Indonesia will reach 34.6 million metric tons, the highest in the Southeast Asia region. The high production of milled rice requires serious attention in every aspect to provide maximum benefits for people's lives. One form of attention is to further develop rice-related research to be able to increase both its quantity and quality to ensure its availability in the future. According to Esa *et al*. (2013), the demand for rice will remain high for decades to come.

White rice is the main product of paddy (*Oriza sativa* L) and paddy is the third most widely cultivated crop in the world. Based on its place of origin, rice is classified into three subspecies, namely indica, japonica, and javanica (Morishita *et al*., 1987; Londo *et al*., 2006; Dunna & Roy, 2013; Wang et *al*., 2014). Dunna and Roy (2013) stated that japonica rice is found mainly in Japan, javanica is mainly grown in Indonesia, and indica is cultivated all over tropical and sub-tropical Asia. In terms of shape, indica is slender somewhat flat grains, japonica is short roundish grains, and javanica is broad thick grains. These three types of rice grains have different characteristics. Their quality and quantity are heavily influenced by many factors, including the milling process applied. The waste resulting from the grain milling process will be produced in the form of husks, rice bran, and groats. The waste from this milling process has a high usefulness value. One of the milling wastes that get a lot of attention is the husk.

Kumar *et al*. (2013) used rice husk as a value-added raw material for various purposes, Anggraeni *et al*. (2022a) used husk as a mixture of vehicle brake pads. Anggraeni *et al*. (2022b) also used husk as a mixture of porous concrete, Anshar *et al*. (2016) used the husk as an activated carbon material, Nurjamil *et al*. (2021) utilized husks as a carbon source for batteries, and Wulandari *et al*. (2021) successfully used the rice husk as fuel for the stove. The properties of a material are very important to be figured out to characterize and utilize the material appropriately according to its potential. One of the important properties of organic materials including white rice is the physicochemical properties. One of the methods to characterize the physicochemical properties of the materials is Fourier Transform Infrared Spectroscopy (FTIR).

This method has been used intensively to characterize a wide variety of materials. Nandiyanto *et al*., (2019) used FTIR for material characterization of *Lumbricus rubellus*, Thakur *et al*. (2019) used it to get characteristics of protein isolated from apricot, Panhwar *et al*. (2019) applied it on castor oil characterization, Obinna (2022) for researching human hair, Sukamto and Rahmat (2023) for compost products.

Based on the results of the FTIR spectra of white rice in the form of flour, the wavenumber of 4000–400 cm^{-1} was indistinguishable. At higher intensity, namely in the 3734.31 cm^{-1} regions, there is O-H stretching (water) in the material. The peak at 2019.54 cm^{-1}, showed the presence of an amine functional group as indicative of protein content (Thakur *et al*., 2020). In addition to the FTIR characterization of the material. It can also be done using a Scanning

Electron Microscope (SEM). SEM will produce images of the sample by scanning the surface of the material. Based on this process, various signals containing information will be generated about the surface topography and composition of the sample. Akhtar *et al.* (2018) stated that SEM is an advanced and useful tool that is widely used to investigate surface phenomena of a material. While Thakur *et al.* (2020) stated that the investigation of the microstructure of a material can determine the microstructure, chemical composition, and physical properties of a material. Yolanda and Nandiyanto (2022) provided detailed steps on how to read and measure the diameter of material using SEM.

Martelo *et al.* (2021) used SEM to characterize the surface topography of coated paperboard, Khan *et al.* (2022) used SEM to investigate the microstructural changes of wheat flours and doughs, and Liu *et al.* (2019) used SEM for corn flour. Meanwhile, Rosli and Ain (2014) reported that the cross-sectional diameters for brown rice and white rice samples were in the range of 847 to 1000 µm. SEM can describe the microscopic conditions of a material surface in detail. In the field of agricultural engineering, this is very important concerning the frictional properties of agricultural grains, both internal friction, and wall friction. Both of these values are needed in the analysis of various agricultural equipment such as the design of silos for agricultural grain storage.

Many factors affect the properties of rice, but one of the most important factors in characterizing various properties of rice is the moisture content. In agricultural products, foods, and other biological materials, water is the most important component that practically forms all the important properties of these materials (Blahovec, 2007). Changes in the moisture content of rice will result in changes in the metabolic process in rice. At high moisture levels, metabolic activity will also increase and vice versa. Meanwhile, metabolic activity will directly affect various properties of the rice such as physical, mechanical, chemical, physiology, rheology, and others. Consequently, when measuring the properties of rice, it is necessary to always consider the effect of the moisture content of the rice. High moisture content in grains will cause high respiration and metabolic activity. Low moisture content respiratory activity will decrease and will be able to maintain product quality during storage (Lisboa *et al*., 2017; Sa *et al*., 2020).

There are various rice grains in the world and many bases for classifying rice are used such as place of origin, grain shape or size, starch content, aroma, milling grade, grain integrity, etc. As aforementioned, based on the place of origin, rice is divided into three subspecies or groups of different varieties, namely japonica, javanica, and indica. However, this classification cannot be a direct illustration of the geometry and dimension of the rice grain. To characterize the physical, mechanical, and rheological properties for engineering purposes, classification based on shape and size is considered more appropriate, because this classification method will be easier to visualize the grain appearance. Based on the grain length, the rice grain can be classified as short, medium, and long grains (Ikehashi, 2009; Dong *et al*., 2010; Tamura *et al*., 2021; Tchuisse *et al*., 2020; Childs & Beau, 2021).

Specifically, the classification method is based on the shape and size of the rice grains as shown in **Table 1** (Normita & Cruz, 2002). This classification is considered to be more appropriate from an engineering point of view. Many studies have revealed the significant influence of grain shape and size on the physical, mechanical, chemical, and other properties of agricultural grains (Tengen *et al*., 2008; El Fawal *et al*., 2009; Emadi *et al*., 2011; Firouzi 2014; Vega-Rojas *et al*., 2016; and Soyoye 2018).

Table 1. Classification of rice according to the size and shape (Normita & Cruz, 2002).

Size Classification	
Size category	**Length (mm)**
Very long	More than 7.50
Long	6.61 to 7.50
Medium	5.51 to 6.60
Short	Less than 5.50
Shape Classification	
Shape category	**Length/Width Ratio**
Slender	More than 3.0
Medium	2.1 to 3.0
Bold	2.0 or less than 2.0

Based on the milling process carried out, rice is classified into rough, brown, and white. Rough rice is the term used for unprocessed rice, brown rice is rice that has undergone the husking process, and white rice is rice that has undergone a whitening process and is ready to be consumed. Generally, the rice traded in the market is in the form of white rice. Therefore, its characteristics must be identified to provide a better understanding of the quality attributes of white rice.

There are many quality attributes commonly used to characterize the quality of white rice, one of the most important properties of white rice and required by many designers and engineers is the mechanical properties of the grain. Mechanical properties are important parameters concerning many processing activities, machine design, and for the development of scientific theories. Similar statements have also been expressed by other researchers (Zareiforoush *et al.*, 2012; Nasirahmadi *et al.*, 2014; Haq *et al.*, 2015; Bhat & Riar 2016).

Many studies have been carried out to explore the properties of agricultural grains. However, there are still limited studies to investigate the mechanical properties of white rice. Kiani *et al.* (2009) worked on red bean grains, Sheifi and Alimardani (2010) reported the physical and mechanical properties of corn, Rodrigues *et al.* (2019) examined sorghum grain, Chandio *et al.* (2021) dealt with the mechanical properties of corn.

White rice grain is a biological material with a small size, its properties are not constant throughout its life, and therefore its mechanical properties are difficult to determine precisely. Its properties depend on many factors during post-harvest handling activities that affect the overall grain properties. One of the most important factors for most agricultural grains including white rice is the moisture content.

The moisture content is known to have a great influence not only on mechanical properties but almost all grain properties are affected by moisture content. Many reports indicate the significant effects of moisture content on grain properties (Kibar & Ozturk, 2008; Maksoud, 2009; Stasiak *et al.*, 2011; Babic *et al.*, 2011; Zareiforoush *et al.*, 2012; Kenghe *et al.*, 2012; Resende *et al.*, 2013; Horabik & Molenda, 2014; Chigbo, 2016; Feng *et al.*, 2019; Etim *et al.*, 2021; Dash *et al.*, 2021; Gierz *et al.*, 2022).

Since grain type and moisture content have a significant influence on grain properties, it is important that in any grain characterization, these two factors are considered. Therefore, it is important to investigate the mechanical properties of white rice concerning grain type and moisture content. This study aimed to determine the effect of grain type and moisture content on the mechanical properties of white rice by using Hertz's theory. The results of this study will provide

volume of the grain would increase too, resulting in longer and thicker grain size, and finally increased the values of R_1 and R_1'. Resende *et al.* (2013) stated that the radius of curvature of rice varied with moisture content. However, there was no certain pattern observed. It was also observed that very-long slender gain had the largest value of R_1' but the smallest value of R_1 this phenomenon reflected that the shape of this grain was very long and thin.

Bamrungwong *et al.* (1987) found that the radius of curvature of indica rice was considerably different from japonica rice. Statistical analysis among the R_1 values indicated that grain type and moisture content significantly affected the value of R_1, however, there was no interaction between the two factors ($p<0.05$). Whereas for the R_1' values, it was found that grain type, moisture content, and interaction of these two factors significantly affected R_1' ($p<0.05$). From means comparison analysis using DMRT, it was obtained that the values of R_1 of the three-grain types and the three moisture contents tested differed from each other (**Tables 4** and **5**).

The relationship between R_1 and R_1' with the moisture content could be expressed satisfactorily as linear regression equations, except for the equation of R_1' for the very long-slender grain which was better to be expressed as a quadratic polynomial equation (**Table 6**). Zuomei *et al.* (2015) found that R_1 tended to increase, while R_1' had no certain pattern with the increase in moisture content for milled grain.

4.2. Angle of Internal Friction

In this study, the internal friction angle (φ) was measured using a direct sheal cell apparatus. It was found that φ increased with moisture content with the rate of increment almost the same for the three-grain types. **Figure 4(b)** presents the values of φ for the three-grain types as the function of moisture content. Some researchers also reported the phenomenon of increasing φ with moisture content, Kibar and Ozturk (2008) for soybean, Kibar *et al.* (2010) for rough rice, Balasubramanian and Viswanathan (2010) for milled, Ozturk and Esen (2013) for corn, Klinkesorn *et al.* (2004) for wheat, and Chigbo (2016) for soybean.

The increase in φ value due to the increase in moisture content was probably due to the surface of the seeds getting wetter at higher moisture content, thereby increasing the cohesive forces between grains which would further increase the φ value. Statistical analysis revealed that grain type, moisture content, and the interaction of these two factors significantly affected φ values ($p<0.05$).

The DMRT analysis revealed that long-medium grain was not significantly different from short-bold grain, while those two-grain types significantly differed from very long-slender grain type (**Tables 4** and **5**). The relationship between φ and moisture content could be expressed as linear equations (**Table 6**). Kibar (2010) also reported that φ of rice grain increased with moisture content in a linear relationship. Bahesti *et al.* (2014) also reported a linear increase of φ with moisture content for two wheat varieties of *Durum* and *Ghods*.

4.3. Poisson's Ratio

The φ values obtained were then used to calculate Poisson's ratios (ϑ) by applying Equation (8). It could be observed that the resulting ϑ values ranged from 0.355 to 0.391, where these values were in the range of ϑ which was commonly suggested in many research reports. The value of Poisson's ratio ranged from 0 to 0.5. Many research works also reported the value of ϑ in that range for different agricultural products, Shitanda *et al.* (2002) for rough rice, Molenda and Stasiak (2002) for wheat, Burubai *et al.* (2008) for nutmeg, Kiani *et al.* (2009) for red bean grain, Sarnavi (2013) for wheat, Moya *et al.* (2013) for barley, oats, sunflower, lentil, wheat, and corn, and Neto *et al.* (2016) for rice. This meant that the suggested equation to compute ϑ was in good agreement with much literature and therefore could be used to estimate the value of ϑ, especially for grain material. It was also observed that the values of ϑ decreased as the moisture contents increased (**Figure 4(c)**), this was an opposite trend as compared with φ. In the other words, the larger the value of φ, the smaller the value of ϑ.

The statistical analysis resulted that grain type, moisture content, and the interaction of these two factors significantly affected ϑ values ($p<0.05$). It was also observed that the values of ϑ for short-bold and long-medium grains were not significantly different but differed with very long-slender grains and had higher values (**Tables 4** and **5**). This was in agreement with the work reported by Shitanda *et al.* (2002) that the short rough rice grain of *Akitakomachi* had a larger value of ϑ than the long rice grains of *Delta* and *L201*. Further, the relationship between ϑ and moisture content could be expressed as a linear equation (**Table 6**). Kiani *et al.* (2009) also found that the value of ϑ for red grain beans increased linearly with moisture content.

4.4. Rupture Force

The compressive strength of the grain samples was measured to determine the maximum force (*F*) when the grain sample was broken. The results revealed that the rupture forces of the samples also varied according to moisture content and grain type. **Figure 4(d)** presents the rupture force of the grains samples as the function of moisture content. The rupture force of all three-grain types was shown to decrease as the moisture content increased. The same phenomenon was also observed by many other researchers, Altuntas and Yildis (2007) for faba bean grain, Khodabakhshian *et al.* (2011) for sunflower seeds, Zareiforoush *et al.* (2012) for paddy, Resende *et al.*, (2013) for rough rice, Nasirahmadi *et al.* (2014) for paddy, Zoumei *et al.* (2015) for milled grain, Nyorere and Uguru (2018) for gmelina seed, Mohite *et al.* (2019) for tamarind seed, Rodrigues *et al.* (2019) for sorghum, Wang and Wang (2019) for corn, and Etim *et al.* (2021) for mucuna bean. It was also observed that the three-grain types had almost the same values of *F*, except for very long-slender grain at a moisture content of 14%, which was quite larger as compared with short-bold and long-medium grains.

These results informed that the rate of decreasing *F* values with increasing moisture content for very long-slender grains was smaller as compared with short-bold and long-medium grains. Statistical analysis revealed that grain type, moisture content, and the interaction between these two factors significantly affected *F* values ($p<0.05$). From means comparations, it was obtained that short-bold and long-medium grains were not significantly different but differed with very long-slender grain types. The very long-slender grain was found to have a larger value of *F* as compared to short-bold and long-medium grains (**Tables 4** and **5**). Shitanda *et al.* (2002) reported that rupture force for a long grain of rough rice was higher than that of short grain rice. The relationships between *F* and moisture content for the three-grain types were adequately expressed as linear equations (**Table 6**). Bagheri *et al.* (2011) reported that the relationship between *F* value of brown rice from 12-grain varieties and moisture content was linear and the *F* value decreased with increasing moisture content for rice. Resende *et al.* (2013) also reported that *F* decreased linearly with increasing moisture content for rough and dehulled rice. Meanwhile, Seifi and Alimardani (2010) reported that *F* of corn grain increased with moisture in the quadratic polynomial.

4.5. Major and Minor Semi-Axis

Minor semi-axis (*b*) is the shorter radius of the ellipse contact area between the compression plate and grain sample. This value is calculated using Equation (5) and the results are depicted in **Figure 4(e)**. It could be observed that the value of *b* tended to increase with moisture content. Short-bold grain was also observed to have the largest *b* value, followed by long-medium grain, and the smallest was for very long-slender grain. This was in contrast with the values of *a*, this meant that as the length of the grain was shorter the value of *b* of that grain would be larger.

Short-bold grain had the largest R_1 but the smallest value of R_1', this caused the value of *b* for japonica to be the largest. On the contrary, the very long-slender grain had the smallest R_1 but the largest R_1', because the value of *a* was the largest. Statistical analysis showed that grain type, moisture content, and the interaction of these two factors significantly affected *b* values ($p<0.05$). Zoumei *et al.* (2015) reported a significant effect of moisture content on *b* values for milled grain. Means comparations revealed that the values of *b* differed for the three-grain types, and the same was true for the three moisture contents tested (**Tables 4** and **5**). A linear relationship between *b* and moisture content was found for the three-grain types tested (**Table 6**).

Major semi-axis (*a*) is the longer radius of the ellipse contact area between the compression plate and grain sample. This value is calculated using Equation (4) and the results are depicted in **Figure 4(f)**. It could be observed that this value increased with the moisture content at almost the same slope for the three-grain types. The very long-slender grain had the largest *a* value, followed by the long-medium grain and the smallest was for short-bold grains. This finding seemed to have a strong correlation with the length of grain types, where the longer the length of the grain, the larger the value of *a* for that grain.

Statistical analysis indicated that grain type, moisture content, and the interaction of these two factors significantly affected the values of *a* ($p<0.05$). Zoumei *et al.* (2015) found that moisture content significantly affected the value of *a* for milled grain. **Tables 4** and **5** show the results of mean comparison using DMRT for the values of *a* for the three-grain types tested. Similar to the value of *b*, the relationship between *a* and moisture content could be satisfactorily expressed using linear equations (**Table 6)**.

4.6. Ellipse Contact Area

Using Equation (9) the ellipse contact area (*Ae*) between the grain sample and the compression plate at rupture can be determined. **Figure 4(g)** presents the results of *Ae* values for the three types of grain as a function of moisture content. It was found that the value of *Ae* increased along with moisture content. Short-bold grain had the largest *Ae* followed by very long-slender grain and the smallest was for long-medium grain. This finding is consistent with the results reported by Shitanda *et al.* (2002) where short rough rice grain was found to have a slightly higher contact area compared to long rice grain. Statistical analysis showed that grain type, moisture content, and the interaction of those two factors significantly affected *Ae* values ($p<0.05$).

Means comparison of *Ae* values for the three-grain types tested informed that *Ae* differed both according to the grain type and the moisture content (**Table 4** and **5**). The relationship between *Ae* and moisture content for very long-slender grain tended to have a linear pattern. However, short-bold grain and long-medium grain were better to be expressed as the polynomial equations (**Table 6**). These results showed that for short-bold grain and long-medium grain types, the values of *Ae* were almost constant from 9 to 14% of moisture contents, however, increased quite large beyond 14% of moisture content.

4.7. Maximum Pressure

S_{max} is the maximum pressure in the grain material when the grain is compressed and this occurs at the center of the contact point between the grain and the compression plate. S_{max} is calculated from the value of compression force at rupture divided by *Ae*. **Figure 4(h)** presents the values of S_{max} for the three-grain types as the function of moisture content. It could be seen that S_{max} decreased along with the increase in moisture content. It was reasonable since as the moisture content increased, the grain would become softer and their strength becomes weaker, as a result, their resistance to the compression stress would also decrease.

The same phenomenon was observed by Zoumei *et al.* (2015) for milled grain and Buggenhout *et al.* (2013) for raw and parboiled rice. It could also be found that short-bold grain seemed to have the lowest value of S_{max}, while long-medium and very long-slender grains were almost the same. These findings were in agreement with the one reported by Bamrungwong *et al.* (1987) for rice grain, where long grain had a larger breaking force than short grain. Visually could be observed that short-bold grains had a smaller grain size as compared to long-medium and very long-slender grains. This smaller grain size might need lower compression stress to break than the larger ones, which caused the lower value of S_{max} for short-bold grain type. Statistical analysis showed that grain type, moisture content, and the interaction of these two factors significantly affected S_{max} values ($p<0.05$). From the comparison of the means, the three-grain types were different from each other, and the same was true given the moisture content tested (**Tables 4** and **5**). The relationship between S_{max} and the moisture content of the three-grain types was also found to be linear (**Table 6**).

4.8. Deformation

Deformation (*D*) of the grains is a decrease in grain height or thickness when the grain is being compressed, and this value is calculated using Equation (11). **Figure 4(i)** presents the results of this calculation for the three-grain types as the function of moisture content. It could be observed that *D* increased with moisture content in all three-grain types. Nyorere and Uguru (2018) reported the same phenomenon for gmelina seeds and Fadeyibi *et al.* (2021) for miracle berry fruit. Short-bold were also found to have the highest value of *D* while long-medium and very long-slender grains were almost the same. Short-bold grain was the thickest among the grain types tested.

Therefore, when it was compressed normally to the thickness of the grain, the availability of the distance in the vertical direction for the cells to move in the internal of the grain would be more available, this probably caused the deformation to be the largest. Bamrungwong *et al.* (1987) reported that short-bold grain had larger deformation than long-slender grain at the same moisture content. Shitanda *et al.* (2002) also reported that short rough rice grain (*Akitakomachi*) had larger deformation than long rice grain (*LD201* and *Delta*). Statistical analysis showed that grain type, moisture content, and the interaction between these two factors significantly affected *D* values ($p<0.05$).

The mean comparison resulted that *D* for long-medium and very long slender grains were not significantly different, however, they differed with short-bold grains (**Tables 4** and **5**). The value of *D* for very long-slender grains tended to increase linearly with moisture content, while shot-bold and long-medium grains showed a non-linear pattern with increases in moisture content. For this reason, the relationship of *D* with the moisture content for short-bold and long-medium grains was determined as a polynomial equation (**Table 6**). A similar phenomenon was reported by Altuntas and Yildiz (2007) for faba bean and Resende *et al.* (2013) for milled rice.

5. CONCLUSION

The moisture content, grain type, and the interaction of these two factors had a significant influence on most parameters of the mechanical properties of white rice ($p<0.05$). The values of R_1, R_1', φ, *a*, *b*, *Ae*, and

D increased while ϑ, *F*, and S_{max} decreased with the increase in moisture contents for the three-grain types. In general, the relationship between the mechanical parameters of white rice and moisture content could be expressed by a linear equation, except for R_1' for very long-slender grain (*Basmati*), *Ae* and *D* for short-bold grain (*Koshihikari*) and medium-length grain (*IR 64*) which were better expressed in quadratic polynomial equations. The equation for determining ϑ based on the value of φ showed a good agreement with the commonly suggested ϑ values.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the data and the paper are free of plagiarism.

8. REFERENCE

Abasi, S., and Minaei, S. (2014). Effect of drying temperature on mechanical properties of dried corn. *Drying Technology: An International Journal*, *32*(7), 774-780.

Akhtar, K., Khan, S. A., Khan, S. B., and Asiri, A. M. (2018). Scanning electron microscopy: Principle and applications in nanomaterials characterization. *Handbook of Materials Characterization*, *2*, 113-145.

Altuntas, E., and Yildiz, M. T. (2007). Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. *Journal of Food Engineering*, *78*, 174-183.

Altuntaş, E., Gul, E. N., and Bayram, M. (2013). The physical, chemical and mechanical properties of medlar (*Mespilus germanica* L.) during physiological maturity and ripening period. *Journal of Agricultural Faculty of Gaziosmanpasa University*, *30*(1), 33-40.

Anggraeni S., Nandiyanto, A. B. D., Hofifah, S. N., Sitanggang, J. E., Latifah, N. Z., Sopian, O., Saputra, Z. (2022b). effect of biomass comparison of rice straw and eggshell in a porous concrete mixture. *Journal of Engineering Science and Technology*, *17*(3), 1857 – 1866.

Anggraeni, S., Anshar, A. N., Maulana, A., Nurazizah, S., Nurjihan, Z., Putri, S. R., and Nandiyanto, A. B. D. (2022a). Mechanical properties of sawdust and rice husk brake pads with variation of composition and particle size. *Journal of Engineering Science and Technology*, *17*(4). 2390 – 2401.

Anshar, A. M., Taba, P., and Raya, I. (2016). Kinetic and thermodynamics studies on the adsorption of phenol on activated carbon from rice husk activated by ZnCl2. *Indonesian Journal of Science and Technology*, *1*(1), 47-60.

Anthony, M. C., Teng, P., Lassa, J., Nair, T., and Shrestha, M. (2016). Public stockpiling of rice in Asia Pacific. *NTS Report*, *3*, 1-61.

Babic, L., Radojčin, M., Pavkov, I., Turan, J., Babic, M., and Zoranović, M. (2011). Physical properties and compression loading behaviour of corn (*Zea mays* l.) seed. *Journal on Processing and Energy in Agriculture, 15*(3), 118-126.

Bagheri, I., Dehpour, M. B., Payman, S. H., and Zareiforoush, H. (2011). Rupture strength of brown rice varieties as affected by moisture content and loading rate. *Australian Journal of Crop Science, 5*(10), 1239-1246.

Balasubramanian, S., and Viswanathan, R. (2010). Influence of moisture content on physical properties of minor millets. *Journal of Food Science and Technology, 47*(3), 275-280.

Bamrungwong, S., Satake, T., Vargas, D., and Yoshizaki, S. (1987). Fundamental studies on mechanical properties of long grain rice varieties: I compressive properties of long grain rice. *Japanese Journal of Tropical Agriculture, 31*(4), 232-240.

Bandumula, N. (2018). Rice production in Asia: Key to global food security. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *88*(4), 1323-1328.

Bhat, F. M., and Riar, C. S. (2016). Cultivars effect on the physical characteristics of rice (rough and milled)(Oryza Sativa L.) of temperate region of Kashmir (India). *Journal of Food Science and Technology*, *53*(12), 4258-4269.

Blahovec, J. (2014). Role of water content in food and product texture. *International Agrophysics*, *21*, 209-215.

Buggenhout, J., Brijs, K., Celus, I., and Delcour, J. A. (2013). The breakage susceptibility of raw and parboiled rice: A review. *Journal of Food Engineering, 117*(3), 304-315.

Burubai, W., Amula, E., Davies, R. M., Etekpe, G. W. W., and Daworiye, S.P. (2008). Determination of poisson's's ratio and elastic modulus of African nutmeg (*Monodora myristica). International Agrophysics, 22*, 99-102.

Chandio, F. A., Li, Y., Ma, Z., Ahmad, F., Syed, T. N., Shaikh, S. A, and Tunio, M. N. (2021). Influences of moisture content and compressive loading speed on the mechanical properties of maize grain orientations. *International Journal of Agricultural and Biological Engineering, 14*(5), 41–49.

Che, Q., Xu, P., Li, Z., Ma, W., and Yao, S. (2020). Crashworthiness analysis of a multi-layered bi-directionally corrugated steel plates structure. *Science Progress, 103*(3), 1-26.

Chigbo, E. O. J. (2016). Selected physical properties of soybean in relation to storage design. *International Journal of Engineering Research and Applications*, *6*(2), 71-75.

Childs, N. W., and LeBeau, B. (2021/22). Rice import forecast lowered 2.0 million cwt. Rice Outlook: October 2021, RCS-21I, U.S. *Department of Agriculture, Economic Research Service, 14,* 1-15.

Correa, P. C., da Silva, F. S. Jaren, C., Junior, P. C. A., and Arana, I. (2007). Physical and mechanical properties in rice processing. *Journal of Food Engineering*, *79*, 137-142.

Dash, B. S., Swain, S. K., Behera, D., Rayaguru, K., Meshram, M. (2021). Effect of moisture content on engineering properties of green gram for designing of agricultural equipment. *Asian Journal of Dairy and Food Research, 41*, 47-55.

Ding, S., Rotter, M., Ooi, J., Enstad, G., and Xu, D. (2013). Normal pressures and frictional tractions on shallow conical hopper walls after concentric filling: Predictions and experiments. *Chemical Engineering Science, 89*, 264-272.

Dong, R., Lu, Z., Liu, Z., Koide, S., and Cao, W. (2010). Effect of drying and tempering on rice fissuring analysed by integrating intra-kernel moisture distribution. *Journal of Food Engineering, 97*(2), 161-167.

Dunna, V., and Roy, B. (2013). Rice (*Oryza sativa* L.) breeding, biotechnology and seed production of field crops. *Chapter*, *4*, 71-122.

El Fawal, Y. A., Tawfik, M. A., and El Shal, A. M. (2009). Study on physical and engineering properties for grains of some field crops. *Misr Journal of Agricultural Engineering, 26*(4), 1933-1951.

El Hamed, K. E. A. (2015). Variation for fruit morphological, chemical and seed physical traits in three *Cucurbita pepo* L. genotypes. *Catrina, 14*(1), 53-65.

Emadi, B., Khodabakhshian, R., Fard, M. H. A., and Sadrnia, H. (2011). Experimental comparison of applying different theories in elasticity for determination of the elasticity modulus of agricultural produce, pumpkin seed as a case study. *Journal of Agricultural Technology*. *7*(6), 1495-1508.

Esa, N. M., Ling, T. B., and Loh Su Peng. (2013). By-products of rice processing: An overview of health benefits and applications. *Journal of Rice Research: Open Access*, *1*(1), 1-11.

Etim, P. J., Alonge, A. F., and Akpan, G.E. (2021). Effect of moisture content on some mechanical and frictional properties of mucuna bean (*Mucuna crens*) relevant to its cracking. *Agricultural Engineering International: CIGR Journal*, *23*(4), 265-273.

Fadeyibi, A., Lamidi, W. A., and Ademola, S. M. (2021). Engineering and proximate properties of miracle berry fruit (*Synsepalum dulcificum* L.). *Agricultural Engineering International: CIGR Journal, 23*(4), 227-235.

Feng, J., Wu, Z., Qi, D., Jin, Y., and Wu, W. (2019). Accurate measurements and establishment of a model of the mechanical properties of dried corn kernels. *International Agrophysics, 33*, 373-381.

Firouzi, S. (2014). Effect of pre-milling on milled rice breakage – a review. *Thai Journal of Agricultural Science*, *47*(4), 241-250.

Fukugawa, N. K., and Ziska, L. H. (2019). Rice: Important for global nutrition. *Journal of Nutritional Science and Vitaminology, 65*, S2-S3.

Gierz, L., Kolankowska, E., Markowski, P., and Koszela, K. (2022). Measurements and analysis of the physical properties of cereal seeds depending on their moisture content to improve the accuracy of DEM simulation. *Applied Sciences, 12*(549), 1-15.

Glangchai, P., and Rangsri, W. (2021). Effects of pressure soaking on elastic modulus of steamed-cooked glutinous rice kernel. *Trends in sciences, 18*(22), 1-9.

Haq, R., Wani, M., and Prasad, K. (2016). Engineering properties of high and low altitude rice varieties from Kashmir valley at different processing levels. *Cogent Food and Agriculture, 2*(1133371), 1-11.

Horabik, J., and Molenda, M. (2014). Mechanical properties of granular materials and their impact on load distribution in silo: A review. *Scientia Agriculturae Bohemica*, *45*(4), 203–211.

Hussein, N. (2017). Materials Science and Engineering. *International Energy and Environment Foundation, 2017*, 74-79.

Ikehashi, H. (2009). Why are there indica type and japonica type in rice? — history of the studies and a view for origin of two types. *Rice Science*, *16*(1), 1-13.

Kenghe, R. N., Shirkole, S. S., and Nimkar, P. M. (2012). Effect of elevated moisture content on physical properties of soybean. *Thai Journal of Agricultural Science, 45*(3), 127-133.

Khan, M. J., Jovicic, V., Zbogar-Rasic, A., and Delgado, A. (2022). Enhancement of wheat flour and dough properties by non-thermal plasma treatment of wheat flour. *Applied Sciences*, *12*(7997), 1-19.

Khodabakhshian, R., and Emadi, B. (2011). Determination of the modulus of elasticity in agricultural seeds on the basis of elasticity theory. *Middle-East Journal of Scientific Research, 7*(3), 367-373.

Kiani, M. K. D., Maghsoudi, H., and Minaei, S. (2009). Determination of Poisson's ratio and young's modulus of red bean grains. *Journal of Food Process Engineering, 34*(5), 1-11.

Kibar, H., and Öztürk, T. (2008). Physical and mechanical properties of soybean. *International Agrophysics*, *22*, 239-244.

Kibar, H., Öztürk, T., and Esen, B. (2010). The effect of moisture content on physical and mechanical properties of rice (*Oryza sativa* L.). *Spanish Journal of Agricultural Research, 8*(3), 741-749.

Kibar, H., Öztürk, T., and Temizel, K. E. (2014). Effective engineering properties in the design of storage structures of post-harvest dry bean grain. *Acta Scientiarum-Agronomy, 36*(2), 147-158.

Klinkesorn, U., Sophanodora, P., Chinachoti, P., and McClements, D. J. (2004). Stability and rheology of corn oil-in-water emulsions containing maltodextrin. *Food Research International*, *37*(9), 851-859.

Kumar S., Sangwan P., Dhankhar R. M. V., and Bidra S. (2013). Utilization of rice husk and their ash: A review. *Research Journal of Chemical and Environmental Sciences*, *1*(5), 126-129.

Lin, H. I., Yu, Y. Y., Wen, F. I., and Liu, P. T. (2022). Status of food security in east and southeast asia and challenges of climate change. *Climate, 10*(40), 1-35.

Lisboa, C. F., De Araújo, R. S. L., Teixeira, I. R., Mota, J. H., Da Silva, A. G., De Araújo, M. E. V., Silva, D. D. A., França, E. E., Silva, I. L., and De Camargo, F. R. T. (2017). Influence of water content on the quality of pigeonpea seeds. *American Journal of Plant Sciences*, *8*, 2397-2406.

Liu, J., Yuan, T., Wang, R., Liu, Y., and Fang, G. (2019. The properties and tortilla making of corn flour from enzymatic wet-milling. *Molecules*, *24*(2137), 1-16.

Logo, B. A., and Vásárhelyi, B. (2020). Parametric study on the connection between Poisson's's ratio, GSI and environmental stress. *Cames*, *27*(2-3), 205-217.

Londo, J. P., Chiang, Y. C., Hung, K. H., Chiang, T. Y., and Schaal, B. A. (2006). Phylogeography of Asian wild rice, Oryza rufipogon, reveals multiple independent domestications of cultivated rice, Oryza sativa. *Proceedings of the National Academy of Sciences*, *103*(25), 9578-9583.

Maksoud, M. A. F. A. (2013). Mechanical properties of corn kernels. *Misr Journal of Agricultural Engineering*, *26*(4), 1901- 1922.

Martelo, J. B., Andersson, M., Liguori, C., and Lundgren, J. (2021). Three-dimensional scanning electron microscopy used as a profilometer for the surface characterization of polyethylene-coated paperboard. *Nordic Pulp and Paper Research Journal*, *36*(2), 276-283.

Mir, S. A., Bosco, S. J. D., and Sunooj, K. V. (2013). Evaluation of physical properties of rice cultivars grown in the temperate region of India. *International Food Research Journal*, *20*(4), 1521-1527.

Mohite, A. M., Sharma, N., and Mishra, A. (2019). Influence of different moisture content on engineering properties of tamarind seeds. *Agricultural Engineering International: CIGR Journal*, *21*(1), 220-224.

Molenda, M., and Stasiak, M. (2002). Determination of the elastic constants of cereal grains in a uniaxial compression test. *International Agrophysics*, *16*, 61-65.

Morishita, T., Fumoto, N., Yoshizawa, T., and Kagawa, K. (1987). Varietal differences in cadmium levels of rice grains of Japonica, Indica, Javanica, and hybrid varieties produced in the same plot of a field. *Soil Science and Plant Nutrition*, *33*(4), 629-637.

Moya, M., Aguado, P. J., and Ayuga, F. (2013). Mechanical properties of some granular agricultural materials used in silo design. *International Agrophysics, 27*, 181-193.

Muthayya, S., Sugimoto, J. D., Montgomery, S., and Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, *1324*, 7–14.

Nandiyanto, A. B. D., Oktiani, R., and Ragadhita, R. (2019). How to read and interpret FTIR Spectroscope of organic material. *Journal of Science and Technology*, *4*(1), 97-118.

Nasirahmadi, A., Fard, M. H. A., Emadi, B., and Khazaei, N. B. (2014). Modelling and analysis of compressive strength properties of parboiled paddy and milled rice. *International Agrophysics*, *28*, 73-83.

Neto, J. P. L., Nascimento, J. W. B. D., Marques, J. I., and Costa, C. A. D. (2016). Mechanical properties of grain in silos for simulation designs. *Journal of the Brazilian Association of Agricultural Engineering*, *36*(4), 573-580.

Normita, M., and Cruz, D. (2002). Rice grain quality evaluation procedures. *Graham R. A Proposal for IRRI to establish a grain quality and nutrition research centre: IRRI discussion paper series*, *44*, 7-12.

Nueva, J., Tanaleon, J. A., and Besa, A. (2022). Rice tariffication law: Education and views of farmers in the southern Philippines. *ASEAN Journal of Science and Engineering Education*, *2*(2), 143-146.

Nurjamil, A. M., Wolio, N. A., Laila, R. N., Rohmah, S. A., Nandiyanto, A. B. D., Anggraeni, S., and Kurniawan, T. (2021). Eco-friendly batteries from rice husks and wood grain. *ASEAN Journal of Science and Engineering, 1*(1), 45-48.

Nyorere, O., and Uguru, H. (2018). Effect of loading rate and moisture content on the fracture resistance of beechwood (*Gmelina arborea*) seed. *Journal of Applied Science and Environmental Management*, *22*(10), 1609-1613.

Obinna, E. M. (2022). Physicochemical properties of human hair using Fourier Transform Infra-Red (FTIR) and scanning electron microscope (SEM). *ASEAN Journal for Science and Engineering in Materials, 1*(2), 71-74.

Öztürk, T., and Esen, B. (2013). Physical and mechanical properties of some hybrid corn varieties. *International Journal of Agricultural and Biological Engineering*, *6*(1), 111-116.

Panhwar, T., Mahesar, S. A., Kandhro, A. A., Sheerazi, S. T. H , Kori, A. H., Laghari, Z. H., Memon, J. R. (2019). Physicochemical composition and FTIR characterization of castor seed oil. *Ukrainian Food Journal*, *8*(4), 778-787.

Parnsakhorn, S., and Noomhorm, A. (2008). Changes in physicochemical properties of parboiled brown rice during heat treatment. *Agricultural Engineering International: the CIGR E-Journal, 2008*, 1-20.

Resende, O., Correa, P. C., de Oliveirac, G. H. H., Goneli, A. L. D., and Jaren, C. (2013). Mechanical properties of rough and dehulled rice during drying. *International Journal of Food Studies*, *2*, 158–166.

Rodrigues, G. B., Resende, O., de Oliveira, D. E. C., Silva, L. C. M., and Junior, W. N. F. (2019). Mechanical properties of grains sorghum subjected to compression at different moisture contents. *Journal of Agricultural Science*, *11*(4), 279-287.

Rosli, W. I. W., and Ain, I. N. (2014). Morphological characterizations of selected brown rice commercially available in east coast of peninsular Malaysia. *Annals of Microscopy*, *14*, 1-17.

Sá, N. D., Wenneck, G. S., and Saath, R. (2020). Peanut storage with different water content conditions. *International Research Journal of Advanced Engineering and Science*, *6*(1), 1-4.

Sarker, M. S. H., Hasan, S. M. K., Ibrahim, M. N., Aziz, N. A., and Punan, M. S. (2017). Mechanical property and quality aspects of rice dried in industrial dryers. *Journal of Food Science and Technology*, *54*(12), 1-6.

Sarnavi, H. J., Mohammadi, A. N., Motlagh, A. M., and Didar, A. R. (2013). DEM model of wheat grains in storage considering the effect of moisture content in direct shear test. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(3), 829-841.

Segal, R., and Minh, L. N. (2019). Unfair harvest-The state of rice in Asia. *Oxfam GB for Oxfam International, 2019*, 1-32.

Seifi, M. R., and Alimardani, R. (2010). The moisture content effect on some physical and mechanical properties of corn (Sc 704). *Journal of Agricultural Science*, *2*(4), 125-134.

Shakri, A. N. N., Kasim, K. F., and Rukunudin, I. B. (2020). Chemical compositions and physical properties of selected Malaysian rice: A review. *IOP Conference Series: Earth and Environmental* Science, 765, 1-6.

Sharma, K., and Kumar, D. (2017). Elastoplastic stability and failure analysis of FGM plate with temperature dependent material properties under thermomechanical loading. *Latin American Journal of Solids and Structures*, *14*, 1-26.

Shitanda, D., Nishiyama, Y., and Koide, S. (2002). Compressive strength properties of rough rice considering variation of contact area. *Journal of Food Engineering*, *53*, 53–58.

Soyoye, B. O., Ademosun, O. C., Agbetoye, L. A. S. (2018). Determination of some physical and mechanical properties of soybean and maize in relation to planter design. *Agricultural Engineering International: CIGR Journal, 18*(1), 82-89.

Stasiak, M., Molenda, M., Opaliński, I., and Błaszczak, W. (2013). Mechanical properties of native maize, wheat, and potato starches. *Czech Journal of Food Sciences*, *31*(4), 347–354.

Sukamto, S., and Rahmat, A. (2023). Evaluation of FTIR, macro and micronutrients of compost from black soldier fly residual: In context of its use as fertilizer. *ASEAN Journal of Science and Engineering, 3*(1), 21-30.

Tamura, M., Singh, J., Kumagai, C., Kaur, L., and Ogawa, Y. (2021). Cooking of short, medium and long-grain rice in limited and excess water: Effects on microstructural characteristics and gastro-small intestinal starch digestion *in vitro*. *Food Science and Technology*, *146*(111379), 1-9.

Tchuisse, M. N., Tekeu, H., Ngonkeu, E. L. M., Malaa, D. K., Mballa, T., Boudjeko, T., Hubert, J., Galani, Y., and Nji, A. (2019). Grain morphological characterization and protein content of sixty-eight local rice (*Oryza sativa* L) cultivars from Cameroon. *African Journal of Plant Science*, *14*(1), 24-35.

Tengen, T. B., Wejrzanowski, T., and Kurzydlowski, K. J. (2008). The effect of grain size distribution on the mechanical properties of nanometals. *Solid State Phenomema*, *140*, 185-190.

Thakur, A., Vaidya, D., Kaushal, M., Gupta, A., and Verma, A. (2019). Physicochemical properties, FTIR spectra, scanning electron microscopy and functional properties of protein isolate produced from wild apricot kernel press cake. *International Journal of Scientific and Engineering Research*, *10*(9), 318-328.

Thakur, A., Vaidya, D., Kaushal, M., Gupta, A., and Verma, A. (2019). Physicochemical properties, FTIR spectra, scanning electron microscopy and functional properties of protein isolate produced from wild apricot kernel press cake. *International Journal of Scientific and Engineering Research*, *10*(9), 219-328.

Vega-Rojas, L. J., Padilla, M. C., Londoño, N. R., López, A .D. R., Garcia, R. M. L., Rojas, N. P., and Garcia, M. E. R. (2016). The effect of maize grain size on the physicochemical properties of isolated starch, crude maize flour and nixtamalized maize flours. *Agricultural Sciences*, 7, 114-125.

Voicu, G., Ungureanu, N., Tudosie (Stefan), E. M., and Constantin, G. A. (2013). Some mechanical characteristics of wheat seeds obtained by uniaxial compression tests. *U.P.B. Scientific Bulletin, Series D: Mechanical Engineering*, *75*(4), 265-278.

Wang, B., and Wang, J. (2019). Mechanical properties of maize kernel horny endosperm, floury endosperm and germ. *International Journal of Food Properties*, *22*(1), 863-877.

Wang, C. H., Zheng, X. M., Xu, Q., Yuan, X. P., Huang, L., Zhou, H. F., Wei, X. H., and Ge, S. (2014). Genetic diversity and classification of *Oryza sativa* with emphasis on Chinese rice germplasm. *Heredity*, *112*, 489-496.

Wasala, W. M. C. B., Dharmasena, D. A. N., Dissanayake, T. M. R., and Thilakarathne, B. M. K. S. (2012). Physical and mechanical properties of three commercially grown banana (*Musa acuminata* Colla) cultivars in Sri Lanka. *Tropical Agricultural Research*, *24*(1), 42-53.

Wulandari, A. E., Kusumawardani, S. M., Sabrina, M. A., Arofah, S., Sholihat, S. N. S., Rusdiana, D., Suwandi, T., and Aziz, M. (2021). Design of rice husks gasification stove. *ASEAN Journal of Science and Engineering*, *1*(1), 1-8.

Yolanda, Y. D., and Nandiyanto, A. B. D. (2022). How to read and calculate diameter size from electron microscopy images. *ASEAN Journal of Science and Engineering Education*, *2*(1), 11-36.

Yu, Q., Liang, J., Li, Q., and Li, C. (2021). Development of measurement equipment and experimental and numerical simulation studies for warm forming limits of high-strength steel. *Materials*, *14*(2373), 1-15.

Zareiforoush, H., Komarizadeh, M. H., Alizadeh, M. R., Tavakoli, H., and Masoumi M. (2012). Effects of moisture content, loading rate, and grain orientation on fracture resistance of paddy (*Oryza sativa* L.) grain. *International Journal of Food Properties*, *15*, 89-98.

Zareiforoush, H., Komarizadeh, M. H., and Alizadeh, M. R. (2009). Effect of moisture content on some physical properties of paddy grains. *Research Journal of Applied Sciences, Engineering and Technology*, *1*(3), 132-139.

Zuomei, Y., Jingxin, S., and Yuming, G. (2015). Effect of moisture content on compression mechanical properties and frictional characteristics of millet grain. *Transaction of the Chinese Society of Agricultural Engineering*, *31*(23), 253-260.