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ENGINEERING PROPERTIES OF RICE

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Abstract: Engineering properties of rice is essential for designing of storage bin. The physical properties of rice (ADT-43) namely, size, shape, thousand grains mass, aspect ratio, surface area, volume, bulk density, true density and porosity at moisture content ranging from 11.55 to 26.84% (db) were determined using standard techniques for development of ozone based storage bin. In this case, thousand grains mass, surface area and volume increased from 10.70 to 14.59 g, 14.58 to 16.94 mm^2 and 3.78 to 4.76 mm^3, respectively, with an increase in moisture content from 11.55 to 26.84% (db). Geometric mean diameter, sphericity, aspect ratio, true density and porosity increased from 2.30 to 2.48 mm, 0.45 to 0.46, 33.10 to 34.66%, 961.89 to 975.24 $kg \cdot m^{-3}$ and 26.97 to 29.66%, respectively, with an increase in moisture content from 11.55 to 26.84% (db). These properties are very essential for designing of different parts of ozone based storage bin.

Key words*: rice, engineering properties, storage bin, moisture content, porosity*

INTRODUCTION

Rice (*Oryza sativa L.)* is most commonly consumed cereals and stable food for more than half of the Indians population. It is also a good source of riboflavin, thiamine, dietary fiber and niacin. In India, where 80% of the produced rice is consumed; it contributes 60-90% of the calories of Indian diet. ADT 43 is one of the most popular varieties of rice in Tamil Nadu due to high yielding performance. The insects are easily infesting the rice during storage. Temperature and moisture content of the grain provide the basis for extension of storage period, alternatively upon further processing of grain. According to the Food and Agriculture Organization of the United Nations (FAO), more

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than 20% of the world’s harvested grain is spoiled every year. The major part of this loss is caused by insects and mould activity [1]. It reduces the market value and export potential of the rice. Hence there is a need to design a storage bin to manage the insects during storage. Therefore the engineering properties of rice are very essential for designing a storage bin. The marketing value of rice is depending on its physical qualities like infestation percentage, grain weight, moisture content, damaged rice and discolored rice (%) after the harvesting.

The percentage of whole grain is the most important parameter for the rice processing industry. If the machinery and operations are improperly designed may results rice kernel cracking and breakage and consequently a low marketing price. The knowledge of the engineering properties of the agricultural products is of fundamental importance during the storage chamber design and operating different equipments used in post harvesting processing operations of these products [2]. Physical and mechanical properties are important for design and development of bulk storage chamber and fumigation bin. Angle of repose and static coefficient of friction can be useful in design of storage bin hoppers. The information related to porosity is a paramount importance for studies involving fumigant movement through the bulk grain. In addition, together with moisture content and porosity are the basic parameters for studying the storage of agricultural products and drying and to reduce the quantity and quality loss of the agricultural material until its processing and marketing time. A rice grain bed with low porosity will have greater resistance to ozone fumigant movement during the fumigation process, which may lead to the need for higher power to drive the aeration fans or create the vacuum inside the fumigation bin.

Engineering properties of rice grains are required for designing of machines like thresher, cleaner, grader, separator, hulling, milling, scouring and packaging equipments. It is also essential for design and development of storage chamber and fumigation bin. The engineering properties like, angle of repose and coefficient of friction is play a major role in the designing of feed hopper in storage bin and it decides the bin wall thickness. Density and volume of the cereal grains are the important physical properties for designing of storage chamber at a required capacity. Hence, the moisture dependent engineering properties of cereals are essential for to reduce the quantitative and qualitative losses occur from harvesting to consumption.

For rice kernels it can be seen that increased in moisture content causes increases the lateral and vertical pressure on storage bin walls. Because the increase in pressure requires an increase in the thickness of storage bin wall results costs of construction increase. The objective of this study was to investigate the some engineering properties of rice (ADT 43) in relation to designing parameters of storage bin.

MATERIAL AND METHODS

Raw materials. Rice (ADT-43) was obtained from local mill, Coimbatore, India and used for the study. The rice was cleaned by using destoner and specific gravity separator to remove all foreign materials.

Sample preparation. The initial moisture content of rice was determined using hot air oven at 130˚C until a constant weight was reached [3]. The initial moisture content of rice was found to be 11.55% (db). In order to achieve the desired moisture levels for the study, rice samples were conditioned by adding calculated quantity of water. The samples were kept in a refrigerator at 4±2°C for a period of 5 days for the moisture to distribute uniformly throughout the rice grains. The moisture contents of the rice samples were equilibrated to 11.55, 13.79, 18.63, 22.75 and 26.84% (db). The required quantity of rice sample was withdrawn and equilibrated at room temperature (30±2°C) before conducting different tests [4].

Size and shape. To determine the average size of the rice grains, 100 grains were randomly picked and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured using a Mitutoyo digital vernier calliper having a least count of 0.01 mm. Arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of the rice grains were calculated by using the following relationships [5].

$$D_a = \frac{(L+W+T)}{3} \tag{1}$$

$$D_g = (LWT)^{\frac{1}{3}} \tag{2}$$

where:

D_a [mm] - arithmetic mean diameter,
D_g [mm] - geometric mean diameter,
L [mm] - length,
W [mm] - width,
T [mm] - thickness.

The aspect ratio (R_a) was calculated as:

$$R_a = \frac{W}{L} \tag{3}$$

Shape of rice grains can be expressed in the terms of sphericity (ϕ). It was found to be cylindrical. Sphericity of rice grain was calculated using the following formula [5]:

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{4}$$

Thousand grains mass. One thousand rice kernels from each sample were randomly picked and weighted using digital electronic balance having an accuracy of 0.01 g.

Surface area and volume. The surface area of rice grain was found by using the following relationship:

$$S = \frac{\pi C L^2}{2L - C} \tag{5}$$

where:

$$C = \sqrt{WT} \tag{6}$$

Rice volume (V) was calculated using the following equation:

$$V = \frac{\pi C^2 L^2}{6(2L - C)} \tag{7}$$

Density. Bulk density is the ratio of mass of rice grains (M) to its total (bulk) volume (V). It was determined by filling a known volume of container with rice grains and gently tapped without compact the grains during filling.

$$\rho_b = \frac{M}{V} \tag{8}$$

The true density of rice kernel is defined as the ratio of mass of rice to solid volume occupied. The rice volume was determined using toluene displacement technique.

Porosity. Porosity (ε) of rice grain is the ratio of the volume of internal pores in between the grains to its bulk volume. It was determined using following equation [6, 7]:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) * 100 \qquad (9)$$

where:

ε [%] - porosity,

ρ_b [kg·m^{-3}] - bulk density,

ρ_t [kg·m^{-3}] - true density.

Data analysis. All the tests ware repeated for three times to determine mean value of engineering properties. The data were analyzed statistically using AGRES software (7.01) and regression equation using Microsoft Excel software. The treatments and their interactions were compared at $p \leq 0.01$ and $p \leq 0.05$ level using least square deference test.

RESULTS AND DISCUSSION

Size distribution pattern. Per cent distributions of rice grain dimensions at a moisture content of 11.55% (db) measured. About 88 % of rice had a length from 5.03 to 5.12 mm, about 92 % of rice had a width ranging from 1.69 to 1.72 mm and about 89% of rice had a thickness ranging from 1.39 to 1.44 mm. Minimum, maximum and mean values of the three principal dimension of rice at different moisture contents are presented in Table 1. The data indicated that size of the rice kernel increased with an increase in moisture content from 11.55 to 26.84% (db). The length, width and thickness of rice grains increased from 5.05 to 5.39 mm ($p \leq 0.01$), 1.70 to 1.87 mm ($p \leq 0.01$) and 1.42 to 1.52 mm ($p \leq 0.05$), respectively, with increase in moisture content from 11.55 to 26.84% (db). The changes in the size of rice kernel with increase in moisture content may be due to hygroscopic nature. A greater increase was found to be width (8.93%), thickness (6.76%) and length (6.29%). Tab..2 shows the regression analysis of the experimental data showed a linear correlation between length, width and thickness with moisture content at high coefficient of determination (R^2).

Table.1. Minimum, maximum and mean values of axial dimensions of rice at different moisture contents

M.C.	*Length (mm)*				*Width (mm)*				*Thickness (mm)*			
(db)	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*
11.55	*4.98*	*5.32*	*5.05*	*0.12*	*1.63*	*1.76*	*1.70*	*0.11*	*1.33*	*1.49*	*1.42*	*0.09*
13.79	*5.07*	*5.36*	*5.23*	*0.07*	*1.64*	*1.79*	*1.73*	*0.14*	*1.31*	*1.54*	*1.46*	*0.04*
18.63	*5.16*	*5.41*	*5.31*	*0.14*	*1.71*	*1.84*	*1.80*	*0.06*	*1.36*	*1.58*	*1.49*	*0.03*
22.75	*5.14*	*5.48*	*5.36*	*0.09*	*1.72*	*1.89*	*1.83*	*0.08*	*1.42*	*1.67*	*1.50*	*0.14*
26.84	*5.17*	*5.59*	*5.39*	*0.11*	*1.74*	*1.98*	*1.87*	*0.13*	*1.44*	*1.69*	*1.52*	*0.08*

M.C. - Moisture content ; S.D. - Standard deviation

Mean diameters. Geometric mean diameter and arithmetic mean diameter of rice kernel at different moisture contents are shown in Fig. 1. From the figure, it is seen that the mean diameters of rice kernel increased with increase in moisture content, and established a linear and positive relationship with regression equation of the form:

$$D_g = 0.0112M + 2.1974, (R^2 = 0.9404) \tag{10}$$
$$D_a = 0.0128M + 2.6028, (R^2 = 0.9353) \tag{11}$$

where:

M [%] - moisture content of rice kernels (db).

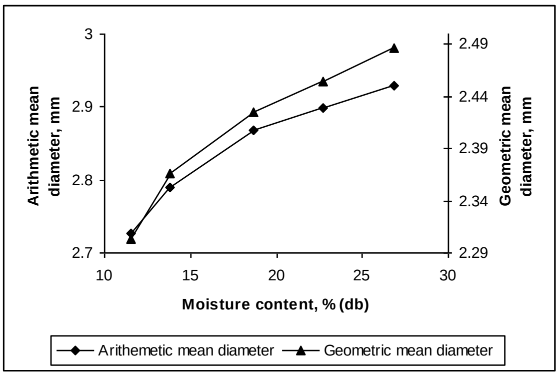

Figure 1. Effect of moisture content on arithmetic and geometric mean diameter of rice

High coefficient of determination (R^2 > 0.93) indicated the best fit of regression equations. The changes in the mean diameters of rice kernel with increase in moisture content might be due to swelling of rice by absorbing moisture [8]. The increase in moisture content from 11.55 to 26.84% (db) increased the arithmetic and geometric mean diameter of rice kernel from 2.72 to 2.92 mm ($p \leq 0.01$) and 2.30 to 2.48 mm ($p \leq 0.01$), respectively. A greater increase was found to be geometric mean diameter (7.33%) as compared to arithmetic mean diameter (6.93%) with increase in moisture content from 11.55 to 26.84% (db).

Aspect ratio. From the Fig.2, it is seen that aspect ratio of rice grain increased from 33.10 to 34.66% ($p \leq 0.05$) with increase in moisture content from 11.55 to 26.84% (db). Thus, the lower values of the aspect ratio indicate a difficulty in getting the kernels to roll than that of spheroid grains [2]. However, it slides on their flat surfaces. This tendency to either roll or slide should be necessary in the design of hoppers for fumigation and storage bin. The increase in aspect ratio with increase in moisture content was reported by Ghadge and Prasad [2] for rice. This confirms the findings of present study. The relation between moisture content and aspect ratio is linear (Tab. 2.).

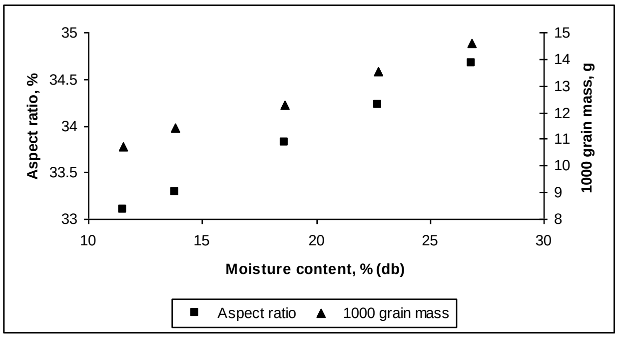

Figure 2. Effect of moisture content on aspect ratio and 1000 grain mass

Mass of thousand grains. Fig. 2 depicted that mass of 1000 rice kernels was found to be increase from 10.70 to 14.59 g ($p \leq 0.01$) with increase in moisture content from 11.55 to 26.84% (db), respectively. The increase in the mass of 1000 rice kernels with increase in moisture content might be due to hysteresis effect of rice kernels. Similar results of effect of grain moisture on thousand grains mass were reported for ridge gourd seed [9] and moth gram [10]. These reported results confirmed the findings of present study. The thousand grain mass is a useful index to “milling outturn” in measuring the relative amount of foreign or dockage material in a given lot of cereal grain, and the amount of immature and shriveled kernels [11].

Shape. The shape of rice was measured in terms of sphericity at different moisture contents are shown in Fig. 3. From the figure, it is seen that the mean value of sphericity increased from 0.455 to 0.460 as the moisture content increased from 11.55 to 26.84% (db), respectively. It indicate that sphericity of rice was significant ($p \leq 0.05$) as the moisture content increased from 11.55% to 26.84% (db). The changes in the sphericity of rice with increase in moisture content might be due to increase in its dimensions namely length, width and thickness. The increase in sphericity upon increase in moisture was reported for barley grains [12] and *Telfaria Occidentalis* seeds [13]. This confirms the findings of the present study. From the Tab. 2, it is seen that a linear relationship exists between moisture content and sphericity of rice grain.

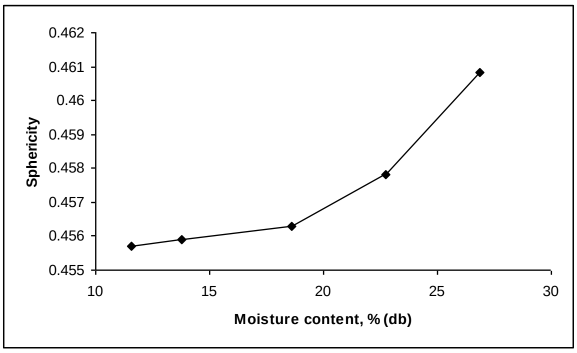

Figure 3. Effect of moisture content on sphericity of rice

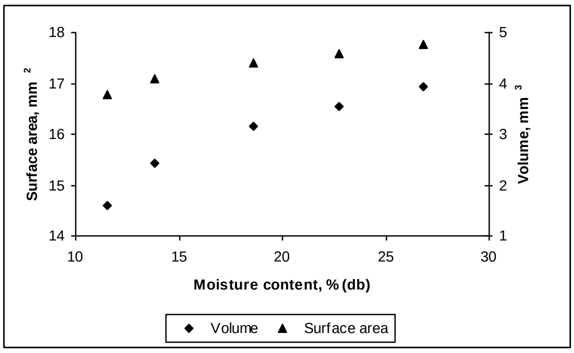

Figure 4. Effect of moisture content on surface area and volume of rice

Surface area. The surface area of rice grain increased linearly from 14.58 to 16.94 mm^2 ($p \leq 0.05$) with increase in moisture content from 11.55 to 26.84% (db) (Fig. 4).

The variation of moisture content and surface area can be expressed mathematically as given in Tab. 2. High R^2 value shows the best fit of equation to the experimental values. The changes in the surface area of rice grain with increase in moisture content may be due to increase in length, width and thickness of rice kernel with increase in moisture content. Similar trends were reported by [14] and [15] for onion seed and linseed, respectively.

Volume. The relationship between volume and moisture content of rice kernel is shown in Fig. 4. The volume of rice grain increased from 3.78 to 4.76 mm^3 ($p \leq 0.01$) as the moisture content increased from 11.55 to 26.84% (db). Similar results were reported by [8] reported an increase in volume with increase in moisture content for onion seed. The linear relationship exists between moisture content and volume followed a regression equation is given in Tab. 2.

Densities. The bulk density of rice grain at different moisture contents are shown in Fig.5. The grains bulk density at different moisture contents varied from 712 to 676 kg·m^{-3}, which indicates a decrease in bulk density with an increase in moisture content from 11.55 to 26.84% (db). That is, 56.96% increase in moisture content resulted in 5.26 per cent decrease in bulk density. The effect of moisture content on bulk density of rice grains showed a significant increase ($p \leq 0.01$) with increasing moisture content. The decrease in bulk density with an increase in moisture content is mainly due to the fact that an increase in mass owing to moisture gain in the sample was lower than accompanying volumetric expansion of the bulk [12]. A similar decreasing trend in bulk density has been reported by [7] for paddy and [16] for pea seed. This confirmed the findings of present study. Regression analysis shows that bulk density is linearly dependent on moisture content and it is negatively correlated.

True density of rice kernel slightly increased with increase in moisture content (Fig. 5). It increased from 961 to 975 kg·m^{-3} with an increase in moisture content from 11.55 to 26.84% (db). That is, 56.96% increase in moisture content resulted in only 1.38 per cent increase in true density. Increasing moisture content had a significant effect ($p \leq 0.05$) on true density of rice. The increase in true density is due to decrease in volume of the kernel at higher moisture content levels. Regression analysis shows (Table. 2) that true density is positively correlated and depicts the linear dependency of true density on moisture content.

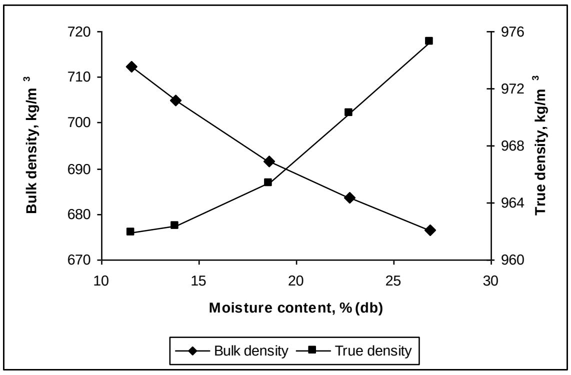

Figure 5. Effect of moisture content on density of rice

Porosity. The effect of moisture content on porosity of rice grain is shown in Fig. 6. From the figure, it was observed that porosity of rice grains increased from 26.97 to

29.66 ($p \leq 0.05$), when the moisture content was increased from 11.55 to 26.84% (db), respectively. The increase in porosity with increase in moisture content might be due to increase in shape and size of rice kernel. From the results, it is seen that, 56.96% increase in moisture content, porosity increased only about 9.06 per cent. The porosity of rice grain followed a linear relationship with moisture content and followed the regression equation (Tab. 2). Similar trend was observed in [14] for onion seed.

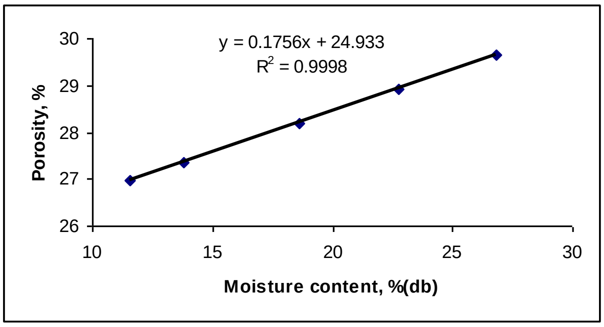

Figure 6. Effect of moisture content on porosity of rice

Table 2. Engineering properties of rice (ADT-43) as a function of moisture content

Engineering properties	*Relationship with moisture content*	*Coefficient of determination (R^2)*
Length (mm)	*0.0197M + 4.9023**	*0.8340*
Width (mm)	*0.0109M + 1.587*	*0.9730*
Thickness (mm)	*0.0061M + 1.363*	*0.9359*
Aspect ratio (%)	*0.1028M + 31.896*	*0.9992*
Thousand grain weight, g	*0.2504M + 7.8261*	*0.9943*
Sphericity	*0.0003M + 0.4515*	*0.8366*
Surface area (mm^2)	*0.0610M + 3.1829*	*0.9556*
Volume (mm^3)	*0.1444M + 13.226*	*0.9375*
Bulk density ($kg \cdot m^{-3}$)	*-2.3212M + 737.23*	*0.9858*
True density ($kg \cdot m^{-3}$)	*0.9307M + 948.92*	*0.9013*
Porosity (%)	*0.1756M + 24.993*	*0.9998*

**M-Moisture content, % (db)*

CONCLUSIONS

Moisture content of rice grains is one of the most important factors influence the storage period of rice. The information on engineering properties of rice (ADT-43) is essential for designing a storage bin and processing equipments. Moisture dependent engineering properties namely size, shape and 1000 grains mass increased with increase in moisture content. The surface area of rice grain increased linearly from 14.58 to 16.94 mm^2 ($p \leq 0.05$) with increase in moisture content from 11.55 to 26.84% (db). The volume of rice grain increased from 3.78 to 4.76 mm^3 ($p \leq 0.01$) as the moisture content increased from 11.55 to 26.84% (db). The grains bulk density at different moisture contents varied from 712 to 676 kg·m^{-3}. True density increased from 961 to 975 kg·m^{-3} with an increase in moisture content from 11.55 to 26.84% (db). The porosity of rice grains increased from 26.97 to 29.66 ($p \leq 0.05$), when the moisture content was increased from 11.55 to 26.84% (db).

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TEHNIČKA SVOJSTVA ZRNA PIRINČA

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Sažetak: Tehnička svojstva pirinča su osnova za projektovanje skladišnog rezervoara. Sledeća svojstva pirinča (ADT-43): dimenzije, oblik, masa hiljadu zrna, površina, zapremina, gustina mase, stvarna gustina i poroznost, pri vlažnosti od 11.55 do 26.84% (db), određivane su standardnim tehnikama za razvoj ozonskog skladišnog rezervoara. U ovom slučaju, masa hiljadu zrna, površina i zapremina porasli su sa 10.70 na 14.59 g, 14.58 na 16.94 mm^2 i 3.78 na 4.76 mm^3, redom, sa povećanjem sadržaja vlage sa 11.55 na 26.84% (db). Geometrijski srednji prečnik, sveričnost, stvarna gustina i poroznost su se povećali sa 2.30 na 2.48 mm, 0.45 na 0.46, 33.10 na 34.66%, 961.89 na 975.24 kg·m^{-3} i 26.97 na 29.66%, redom, sa povećanjem sadržaja vlage sa 11.55 na 26.84% (db). Ova svojstva su osnov za konstruisanje različitih delova ozonskog skladišnog rezervoara.

Ključne reči: *pirinač, tehnička svojstva, skladišni rezervoar, sadržaj vlage, poroznost*

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