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IMPORTANT ENGINEERING PROPERTIES OF PADDY

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Abstract: Engineering properties of paddy is essential for designing of storage bin. The physical properties of paddy (ADT-43) namely, size, shape, thousand paddies mass, aspect ratio, surface area, volume, bulk density, true density and porosity at moisture contents ranging from 11.86 to 23.61% d.b. were determined using standard techniques and these effects on storage chamber design ware evaluated. In the case, thousand paddy mass, surface area and volume increased from 18.24 to 24.07 g, 28.91 to 31.82 mm^2 and 17.55 to 20.52 mm^3, respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Equivalent diameter, sphericity, aspect ratio and bulk density increased from 3.22 to 3.39, 0.41 to 0.42, 30.55 to 31.91% and 568 to 613 kg·m^{-3}, respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Porosity and true density decreased from 46.82 to 38.27% and 1069 to 994 kg·m^{-3} respectively, with an increase in moisture content from 11.86 to 23.61%.

Key words: *paddy, ADT-43, moisture content, physical properties, aspect ratio, equivalent diameter, porosity*

INTRODUCTION

Paddy is one of the stable and leading food crops in India. About 70% of the paddy produced in India was stored at farm level. ADT 43 is the most popular paddy variety grown in all the parts of Tamil Nadu, the reason behind that of ADT 43 are resistant to stem borer and gall midge, high tillering and fine rice. Food grain storage technology

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whether at farm level or commercial level does not fulfill the technical requirements. Food grains are stored in different types of storage structures such as godowns and silo for certain periods till they reach the consumers which play an important role in the proper preservation of food grains. 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 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 indicates the inefficient design of the storage bin. Comprehensive information on physical properties of these materials are most importance for increasing economic importance of food materials, together with the complexity of modern technology for their production, handling, storage processing, preservation, quality evaluation and utilization [2]. The knowledge of some important physical properties of different grains is necessary for the design of various processing equipments and storage chamber [3]. Principal axial dimensions of paddy grains are useful in selecting sieve separators and in calculating power during the rice milling process. They can also be used to calculate surface area and volume of kernels which are important during modeling of grain drying, aeration, heating and cooling [4].

Physical properties of paddy have been investigated and reported by some researchers [4-5]. However, there is a need for a comprehensive study of the engineering properties of paddy is essential for designing of storage bin for ADT-43. Hence the present study was conducted to determine the important engineering properties of paddy viz., shape and size (axial dimensions, equivalent diameter, aspect ratio and sphericity), volume, surface area, true density, bulk density and porosity at five moisture content levels and also to determine how these properties interconnect with moisture content. Paddy as a function of moisture content in the range of 11 to 23% (d.b.) during harvesting to storage operations, which can facilitate in the design of storage bin for whole unit operations.

MATERIAL AND METHODS

Raw Material

Paddy (ADT-43) was obtained from centre farm, located in Tamil Nadu Agricultural University, India and used for the study. The paddy was cleaned manually to remove all foreign materials such as dust, dirt, chaff and immature paddy.

Moisture content determination and sample preparation

The initial moisture content of the paddy was determined using hot air oven at 130˚C for 14-16 h [6]. The initial moisture content of paddy was found to be 11.86 % (d.b.). In order to achieve the desired moisture levels for the study, paddy samples were conditioned by adding calculated quantity of water. The moisture contents of the samples were equilibrated to 11.86, 14.63, 17.51, 20.93 and 23.61% (d.b.) as per the procedures outlined in AOAC (1995) [6]. The required quantity of sample was withdrawn and equilibrated at room temperature (30±2°C) before conducting different tests [7].

Size

The dimensions of paddy such as length (*L*), width (*W*) and thickness (*T*) were measured in mm at five levels of moisture content with the help of a digital vernier caliper having a least count of 0.01 mm. A sample of 100 kernels ware randomly selected from each sample lot having various levels of moisture content from 11.86 to 23.61% d.b. The equivalent diameter (D_p) in mm was calculated through the following expression [8]:

$$D_P = \left[4L\left(\frac{W+T}{4}\right)^2\right]^{\frac{1}{3}} \tag{1}$$

Surface area and volume

The volume (*V*) and surface area (*S*) of paddy was calculated by using the following relationship:

$$V = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T)^2\right] \tag{2}$$

$$S = \frac{\pi B L^2}{2L - B} \tag{3}$$

Where:

$$B = \sqrt{WT} \tag{4}$$

Aspect ratio

The aspect ratio (R_a) is used for classification of paddy shape and it was calculated as [8].

$$R_a = \frac{W}{L} \tag{5}$$

Shape

Shape of paddy can be expressed in the terms of sphericity (ϕ). It is defined as the ratio or the surface area of sphere having the same volume as that of the paddy to the surface area of the paddy was determined as [8].

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{6}$$

Thousand paddies mass

In order to determine mass of thousand paddies approximately 1 kg of paddy sample was roughly divided into 4 equal portions and then 1000 numbers of paddies were randomly picked from each portion and weighed on a digital electronic balance with an accuracy of 0.01 g. The measurement was repeated for 3 times and the mean value was taken as weight of 1000 seeds.

Bulk Density

The bulk density is the ratio of mass of the paddy to its total (bulk) volume. It was determined by filling a circular container of known volume with paddy.

$$\rho_b = \frac{M}{V} \tag{7}$$

Where:
ρ_b [kg·m^{-3}] - bulk density,
M [kg] - mass of the paddy sample
V [m^3 - volume of the container.

True Density

The true density (ρ_t) is the ratio of mass of the paddy to its true volume. It was determined using Toluene displacement method. Toluene (C_7H_8) was used in place of water because paddy absorbed toluene to a lesser extent.

Porosity

The porosity (ε) of the paddy is the ratio of the volume of internal pores in between the paddy to its bulk volume. It was determined using following relationship [8]:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) * 100 \tag{8}$$

Where:
ε [%] - porosity,
ρ_b [kg·m^{-3}] - bulk density,
ρ_t [kg·m^{-3}] - true density.

Data analysis

The data were analyzed statistically using SPSS software and regression equation using Microsoft Excel software.

RESULTS AND DISCUSSION

Size distribution pattern and dimension

Per cent distributions of paddy dimensions at storage moisture content of 11.86% (d.b.) measured. About 94 % of paddy has a length from 7.78 to 7.80 mm, about 91 % of paddy has a width ranging from 2.37 to 2.39 mm and about 89% of paddy has a thickness ranging from 1.75 to 1.78 mm. Minimum, maximum and mean values of the three principal dimensions of paddy at different moisture contents are presented in Table 1. The data indicated that size of the paddy increased with an increase in moisture content. The length increased from 7.79 to 7.99 mm ($P<0.01$); the width from 2.38 to 2.55 mm ($P<0.01$) and thickness from 1.77 to 1.88 mm ($P<0.05$), respectively, with an increase in moisture content from 11.86 to 23.61% d.b. Corresponding value of the IR-36 were the length, width and thickness increased from 9.81 to 9.97 mm, 2.47 to 2.62 mm and 1.93 to 2.05 mm, respectively, with an increase in moisture content from 8.40 to 28.28% d.b. [5]. This data shows ADT-43 variety was smaller than IR-36. A greater increase was found in width (6.66%) and thickness (5.85%) then in length (2.50%). The changes in the size of paddy with increase in moisture content may be due to hygroscopic nature. 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 paddy (ADT-43) at different moisture contents

M.C. (d.b.)	*Length [mm]*				*Width [mm]*				*Thickness [mm]*			
	Min	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*	*Min*	*Max*	*Mean*	*SD*
11.86	*7.78*	*7.80*	*7.79*	*0.01*	*2.36*	*2.39*	*2.38*	*0.02*	*1.73*	*1.78*	*1.77*	*0.02*
14.63	*7.80*	*7.83*	*7.81*	*0.02*	*2.38*	*2.43*	*2.41*	*0.03*	*1.75*	*1.80*	*1.79*	*0.06*
17.51	*7.83*	*7.87*	*7.85*	*0.04*	*2.44*	*2.49*	*2.47*	*0.11*	*1.78*	*1.83*	*1.82*	*0.04*
20.93	*7.88*	*7.94*	*7.91*	*0.03*	*2.48*	*2.52*	*2.50*	*0.09*	*1.81*	*1.86*	*1.84*	*0.01*
23.61	*7.97*	*8.01*	*7.99*	*0.10*	*2.49*	*2.58*	*2.55*	*0.04*	*1.84*	*1.93*	*1.88*	*0.13*

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

Equivalent diameter

The variation in equivalent diameter of paddy at different moisture contents is shown in Fig. 1. The increase in moisture content from 11.86 to 23.61% (d.b.) increased the equivalent diameter of paddy from 3.22 to 3.39 mm ($P<0.01$), respectively. From the figure, it is seen that equivalent diameter of paddy increased with increase in moisture content and established a linear relationship and followed a regression equation of the form as shown in Tab. 2. High coefficient of determination ($R^2 > 0.98$) shows the best fit of models to describe the change in equivalent diameter of paddy within the experimented moisture range.

Aspect ratio

From the Fig.1, it is seen that aspect ratio of paddy increased from 30.55 to 31.91% (P<0.05) with increase in moisture content from 11.86 to 23.61 per cent (d.b.). Thus, the lower values of the aspect ratio indicate a difficulty in getting the kernels to roll than that of spheroid grains [9]. However, it slides on their flat surfaces. This tendency to either roll or slide should be necessary in the design of hoppers for storage bin. The increase in aspect ratio with increase in moisture content was reported by [9] for rice. This confirms the findings of present study. The relation between moisture content and aspect ratio is linear (Tab. 2.).

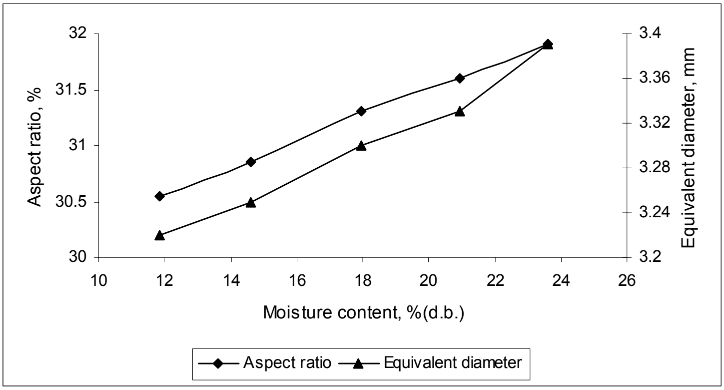

Figure 1. Effect of moisture content on equivalent diameter and aspect ratio of paddy

Shape and thousand grain mass

From the Fig.2, it is seen that sphericity and thousand paddy mass increased from 0.4109 to 0.4218 (P<0.01) and 18.24 to 24.07 g (P<0.01), respectively, with increase in moisture content from 11.86 to 23.61 per cent (d.b.).

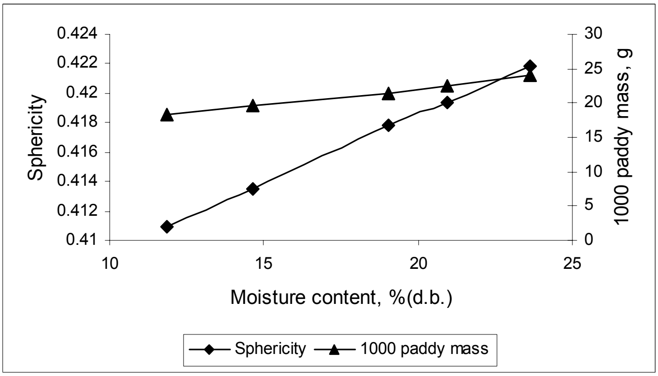

Figure 2. Effect of moisture content on sphericity and thousand mass of paddy

According to [4] considered the grain as spherical when the sphericity value was more than 0.70. Obtained results from this study, ADT 43 should be treated as an equivalent sphere. The changes in the shape of paddy and 1000 grains mass with increase in moisture content may be due to increase of the main paddy dimensions. The increase in sphericity and thousand grain mass with increase in moisture was reported by [2, 4]. This confirms the findings of present study. From the Tab. 2, it is seen that a linear relationship exists between shape and thousand grain mass of paddy with respect to moisture content.

Surface area

The value for surface area of paddy obtained for different moisture content is graphically represented in Fig. 3. The values of paddy surface area increased from 28.91 to 31.82 mm^2 with increase in moisture content from 11.86 to 23.61% (d.b.) and followed a linear regression equation of the form given in Table 2. High R^2 value shows the best fit of equation to the experimental values. The changes in the surface area of paddy with increase in moisture content may be due to increase in dimensions of paddy with increase in moisture content. Similar trends were reported by [10] for hemp seeds, respectively. These findings confirmed the results of present study.

Volume

The experimental results of volume of paddy at different moisture levels are depicted in Fig. 3. The volume of paddy increased from 17.55 to 20.51 mm^3 as the moisture content increased from 11.86 to 23.61% (d.b.). Similar results were reported by [11] reported an increase in volume with increase in moisture content for soybean and barnyard millet grain. The relationship exists between moisture content and volume followed a regression equation form shown in Table 2. High R^2 value indicates the best fit of model to the experiment results.

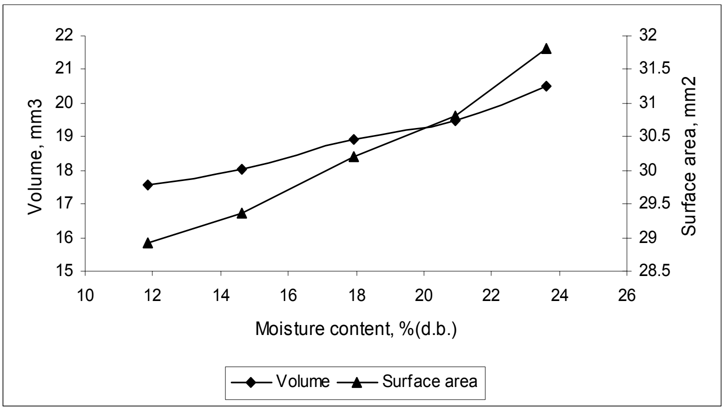

Figure 3. Effect of moisture content on surface area and volume of paddy

Densities

The bulk and true densities of paddy at different moisture contents are shown in Fig.4. Regression analysis shows that bulk density is linearly dependent on moisture content and it is positively correlated. High R^2 value (0.97) shows the best fit of equation to experimental values. The bulk density increased with the increase in moisture content. It increased from 568.51 to 613.68 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). That is, 49.76 per cent increase in moisture content resulted in 7.36 per cent increase in bulk density. The effect of moisture content on bulk density of paddy grains showed a significant increase (P<0.01) with increasing moisture content. The increase in bulk density with an increase in moisture content is mainly due to the increase in paddy volume was less than the corresponding increase in paddy mass of the material. It facilitates the same weight of material to occupy less volume of the cylinder thus increasing the bulk density. Similar results were reported by [12] for onion seeds and [13] for *Telfaria Occidentalis* seeds. This confirmed the findings of present study.

True density of paddy decreased with increase in moisture content. It decreased from 1069.03 to 994.13 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). That is, 49.76 per cent increase in moisture content resulted in only 7 per cent increase in true density. Increasing moisture content had a significant effect (P<0.05) on true density of paddy. The decrease in true density is due to an increase in volume of the kernel (more than weight increase) at higher moisture content levels. Regression analysis shows (Tab. 2) that true density is negatively correlated and depicts the linear dependency of true density on moisture content.

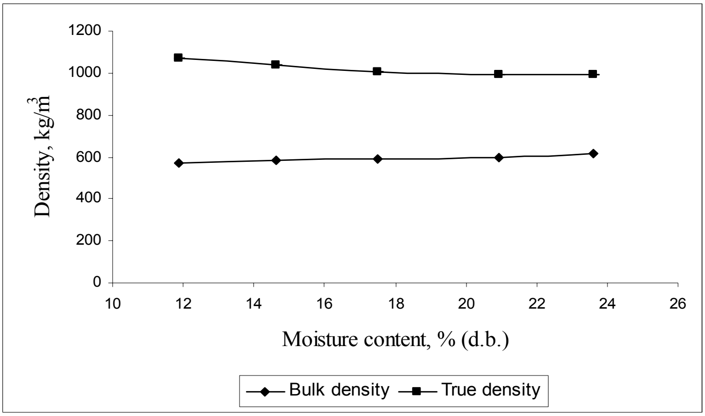

Figure 4. Effect of moisture content on densities of paddy

Porosity

The effect of moisture content on porosity of paddy is shown in Fig. 5. From the figure, it is observed that the porosity of paddy decreased from 46.82 to 38.27 %, when the moisture content was lowered from 23.61 to 11.86 per cent, (d.b.). The reason for this, as the paddy gains moisture increase, its volume increases, thus the number of grains in a fixed volume decreases. Since the number of grains per unit volume decreases, the porosity, i.e. the percent pore space between the particles also decreases [5]. From the results, it is seen that for 49.76 per cent increase in moisture content, the porosity increased by 18.26 per cent. Among the three important physical properties studied namely, bulk density, particle density and porosity, for a unit change in per cent moisture content, the highest percentage change was observed in porosity followed by bulk density and particle density. The porosity of paddy followed a linear relationship with moisture content as given in Table 2. Similar trend was observed in onion seeds [12] and *Telfaria Occidentalis* seeds [13]. This confirmed the results of present study.

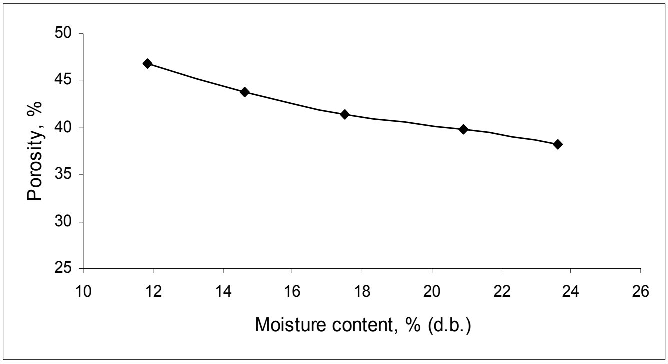

Figure 5. Effect of moisture content on porosity of paddy

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

Engineering properties	*Unit*	*Relationship with moisture content*	*Coefficient of determination (R^2)*
Length	*[mm]*	*0.0168M + 7.5726*	*0.9502*
Width	*[mm]*	*0.0144M + 2.2072*	*0.986*
Thickness	*[mm]*	*0.0090M + 1.66*	*0.9806*
Equivalent diameter	*[mm]*	*0.0141M + 3.0477*	*0.9836*
Aspect ratio	*[-]*	*0.1162M + 29.173*	*0.9994*
Thousand grain weight	*[g]*	*0.4893M + 12.527*	*0.9928*
Sphericity	*[-]*	*0.0009M + 0.4001*	*0.9982*
Surface area	*[mm^2]*	*0.2431M + 25.897*	*0.9830*
Volume	*[mm^3]*	*0.2476M + 14.489*	*0.9840*
Bulk density	*[$kg \cdot m^{-3}$]*	*3.5533M + 527.5*	*0.9753*
True density	*[$kg \cdot m^{-3}$]*	*-6.3838M + 1133.1*	*0.8775*
Porosity	*[%]*	*-0.7034M + 54.492*	*0.9707*

**M-Moisture content, % (d.b.)*

CONCLUSIONS

The information on engineering properties of paddy (ADT-43) which may be useful for designing of equipment for paddy storage bin and processing equipments. Moisture content of paddy is one of the most important factors influence the maintenance of paddy quality. At the moisture content of 11.86% (d.b.), the average length, width and thickness of paddy (ADT-43) were 7.79, 2.38 and 1.77 mm, respectively. The thousand grain weight of the paddy increased from 18.24 to 24.07 g with an increase in moisture content from 11.86 to 23.61% (d.b.). The bulk density increased from 568 to 613 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). The true density decreased from 1069 to 994 kg·m^{-3} with an increase in moisture content from 11.86 to 23.61% (d.b.). Porosity decreased from 46.82 to 38.27% with an increase in moisture content from 11.86 to 23.61% (d.b.). From the results obtained that all the physical properties of paddy are dependent on the moisture contents.

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ZNAČAJNE TEHNIČKE KARAKTERISTIKE ZRNA PIRINČA

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Sažetak: Tehničke karakteristike pirinča su osnove za konstruisanje skladišta. Fizičke osobine pirinča (ADT-43), koje čine: veličina, oblik, masa hiljadu zrna, odnos širine i dužine zrna, površina, zapremina, gustina rasute mase, gustina zrna i poroznost, pri sadržaju vlage od 11.86 do 23.61% , određene su standardnim tehnikama, a zatim su ocenjeni njihovi uticaji na skladišnu komoru. U ovom slučaju, masa hiljadu zrna, površina i zapremina porasle su sa 18.24 na 24.07 g, 28.91 na 31.82 mm^2 i 17.55 na 20.52 mm^3, redom, sa povećanjem sadržaja vlage sa 11.86 na 23.61%. Ekvivalentni prečnik, sveričnost, odnos širine i dužine i gustina rasute mase porasli su sa 3.22 na 3.39, 0.41 na 0.42, 30.55 na 31.91% i 568 na 613 $kg\cdot m^{-3}$, redom, sa povećanjem sadržaja vlage sa 11.86 na 23.61%. Poroznost i gustina zrna smanjile su se sa 46.82 na 38.27% i 1069 na 994 $kg\cdot m^{-3}$, redom, sa povećanjem vlage sa 11.86 na 23.61%.

Ključne reči: *pirinač, ADT-43, sadržaj vlage, fizičke osobine, odnos širine i dužine, ekvivalentni prečnik, poroznost*

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