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The effect of moisture content to the physical properties of long grain paddy (*Oryza sativa*)

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Abstract

A new long-grain rice variety known as MR297 has gained popularity in Malaysia. This cultivar is recognized for its high resistance to rust disease. The physical changes in the long grains of MR297 can be influenced by the moisture content of the paddy. This research examined the moisture-dependent physical characteristics of several Malaysian MR297 paddy cultivar samples at different moisture content levels (16.49, 19.81, 25.36, 28.67, and 34.08%; wet basis). The moisture was adjusted by soaking the rice in excess water, after which it was drained and kept overnight in a closed container at room temperature to obtain equilibrium moisture content before analysis. As the moisture content increased, there were significant increases in the length (10.03 to 10.36 mm), width (2.12 to 2.23 mm), thickness (1.86 to 1.98 mm), aspect ratio (0.21 to 0.22), arithmetic mean diameter (4.67 to 4.68 mm), equivalent mean diameter (3.41 to 3.58 mm), geometrical mean diameter (3.41 to 3.57 mm), sphericity (0.34 to 0.36), surface area (34.81 to 38.04 mm^2), volume (20.81 to 26.57 mm^3) and thousand kernel weight (31.554 to 35.575) (p <0.05). The relationships between the physical characteristics of the MR297 rice cultivars and their moisture content were effectively expressed by linear regression models. The results suggested that increasing the moisture content of grain kernels changes their physical properties. To prevent kernel damage and sustain equipment capacity during processing and handling, changes in physical properties during processing could be considered in equipment design parameters.

Keywords: Moisture content, Physical properties, Rice, MR297

1. Introduction

Rice (*Oryza sativa* L.) is an essential energy source for more than half the world's population and one of its principal crops. This grain is an effective partner against hunger [1]. Since rice is so economically and nutritionally important, investigations into the various forms of processing are important for developing the final product quality. Of the current approaches to rice grain processing, parboilization has acquired consumer and industry favor owing to the nutrition and physical properties involved [2]. The three fundamental steps of parboiling are soaking (hydration), gelatinization (steaming), and dehydration. Although the physical and nutritional impacts of rice parboiling have been widely established, limited information about the process is currently available, particularly the first step. The hydration stage is the most crucial since it is meant to provide the rice with the moisture required for the gelatinization of the starch [3]. During the hydration step, there are crucial changes in both the moisture content and physical properties of the paddy [3].

Each physical property benefits a certain aspect of the further process of parboiling or other types of rice processing. For example, grading by dimensions can be altered by grading by weight because this is more costeffective [4,5]. To achieve maximum efficiency in the design of the apparatus for collecting at the farm and then moving, cleaning, segregating, packing, storing, and analyzing the product's behavior during various agricultural process operations, it is crucial to have comprehensive knowledge of the physical properties of the product. During grading, sorting, sieving, and other separation procedures, the size, shape, and actual dimensions play significant roles. In addition, these characteristics facilitate the calculation of the surface area and volume of biological materials, values which are essential for modeling drying and ventilation [6]. Volume and surface area values can be used to approximate transpiration rates and durations. Moreover, details about volume and its correlation with the packaging coefficient are crucial because knowledge of the packaging coefficients of crops enables more effective quality management during storage [7]. It is generally known that the moisture content of cereal grains affects their physical qualities [4,6]. More specifically, if the moisture level of paddy changes during processing, its physical properties will also change.

Previous researchers have investigated the impact of moisture content on the physical attributes of agricultural products and crops such as chia seeds[8], moringa seeds[9], okra [10], wheat [11], alfalfa seeds [12], quinoa seeds [13], melon [14], rice [4,15,16], green peas [6], maize [4], legumes [4,17,18], and coffee beans [17]. However, only limited studies explored how the physical attributes of MR297 paddy grains are affected by moisture content. Therefore, the aim of this study was to examine the physical properties of MR297 at various moisture content levels. Increased moisture content increases both the horizontal and vertical pressure on the rice kernel storage receptacle walls [7]. Consequently, the moisture-dependent physical attributes of cereal grains are crucial for minimizing both qualitative and quantitative losses between cultivation and consumption.

2. Materials and methods

Fresh paddy MR297 was obtained from a local Malaysian farmer at Kuala Selangor. The paddy was stored using a well-sealed container in a cold room before the experiment (10°C, RH 90±2%). The experiment was conducted in laboratory conditions at room temperature (RH 81±1%). The initial moisture content of the sample was 17.5%.

2.1 Sample preparation

The fresh paddy was manually cleaned and then samples were randomly selected to conduct the analysis. During the experiment, the lowest moisture content was achieved by dehydrating 500 grams of paddy inside a drying oven (Memmert DO6836, Germany) at 40°C for one hour. The moisture content was adjusted by soaking 100 grams of fresh paddy in a glass beaker with 150 mL of distilled water using a continuous slow (scale 2 of 5) shaking water bath (Memmert WNB22, Germany). A hydration curve of the paddy was obtained through preliminary research. The hydration was done by soaking the paddy with water; the moistened paddy was then tempered for one hour at room temperature to eliminate the surface moisture [18,19]. The samples were then put into polyethylene bags, which were then put into a well-sealed polypropylene container and kept in a refrigerator (10°C) until required for further analysis. The analysis of the paddy was conducted at room temperature. The moisture content levels (WB) of the rice samples were adjusted to 16.49, 19.81, 25.36, 28.67, and 34.08%. These moisture content values were within the range encountered in fresh paddy soaked until the moisture content reached equilibrium. Before conducting the various tests, samples weighing ±5 grams were discharged from the storage bag and brought to ambient temperature (30±2°C).

2.2 Dimension measurements

To compute the average size of the paddy grains, one hundred pieces were selected at random and their lengths (L), widths (W), and thicknesses (T) were measured using a Mitutoyo digital vernier caliper with a minimum measurement of 0.01 mm [20,21]. The major (length), medium (width), and minor (thickness) of the axis can be seen in Figure 1. The arithmetic mean diameter (Da), equivalent mean diameter (De), and geometric mean diameter (Dg) of the paddy grains were computed using Equation (1)-(3) [7,22,23]:

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

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

$$D_e = \left(\frac{L\times(W+T)^2}{4}\right)^{1/3} \tag{3}$$

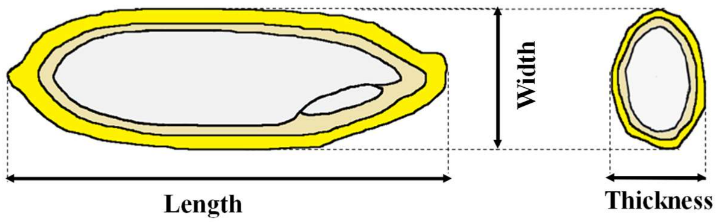

Figure 1 Dimensional characteristics of MR297 paddy grain.

2.3 Sphericity and aspect ratio measurements

The sphericity of a particle means its resemblance to a sphere of equal volume. The aspect ratio is the width-to-height ratio. The aspect ratio (R_a) and sphericity ($\emptyset$) of the rice were computed using Equation (4) and (5) [23-25].

$$R_a = \frac{W}{L} \tag{4}$$

$$\emptyset = \frac{(LWT)^{1/3}}{L} \tag{5}$$

2.4 Surface area, grain volume, and thousand-grain mass determination

The total area of a grain's outer surface is its surface area. Equation (6) was used to compute the surface area of the paddy grain [7,23,24].

$$Sa = \frac{\pi\, C\, L^2}{2L - C} \tag{6}$$

where $C = \sqrt{WT}$.

The paddy grain volume reflects how much space an entire grain takes up. The following formula was utilized to calculate the paddy grain volume [23-25]:

$$V_c = \frac{\frac{\pi}{6} L\,(WT)^2}{4} \tag{7}$$

The thousand-grain mass was calculated using one hundred rice grains randomly chosen from each sample and measured using a digital electronic balance (ER-120A, A&D Company, ltd., Japan) with a resolution of 0.0001 g. The result was then multiplied by ten.

2.5 Statistical analysis

The significant differences obtained from the paddy MR297 with varying moisture content were determined using one-way analysis of variance (ANOVA). Meanwhile, the mean significant differences between the samples' physical properties (length (L), width (W), thickness (T), arithmetic mean diameter (Da), equivalent mean diameter (De), geometric mean diameter (Dg), sphericity, aspect ratio, surface area, grain volume, and thousand-grain mass determination) at each level of moisture content were compared using a Tukey test at $P \leq 0.05$. The data were expressed as means and standard errors using the Minitab Software (Version 19, LLC, USA). The size was determined by averaging 100 granules. A Pearson correlation analysis was undertaken to assess the relationships between the physical properties of the MR297 paddy grains. Meanwhile, the principal component analysis (PCA) was done using the Minitab Software (Version 19, LLC, USA) to visualize the variations among the paddy grain samples having different moisture content by using their physical properties.

3. Results and discussion

3.1 MR297 seed dimensions

Table 1 displays the average experimental results for the dimensional properties of the MR297 paddy at different moisture content levels. The major axis/length (L), medium axis/width (W), minor axis/thickness (T), arithmetic mean diameter (Da), equivalent mean diameter (De), and geometric mean diameter (Dg) all improved significantly with moisture content rises from 16.49% to 34.08% ($p<0.05$). These measurements are crucial for determining the dimensions of machinery openings, especially for machines that separate various substances [26]. Paddy seeds may swell with an increase in moisture. The increase in size due to the higher moisture content levels resulted from the unique moisture absorption characteristics of grain kernels and their diffusion behavior while undergoing the soaking process. The molecular absorption of water changes the size of grains. This happens more in grains with starch and less in grains with a vitreous structure. Vitreous substances are distinguished by their low coefficients of elongation, diffusivity, and specific volume [4].

Similar trends have been observed in wheat [27], Karanja kernel [28], rice [4,15,16,29], green peas [6], maize [4,30], soybeans [4,17,18], pepper berries [31], and coffee beans [17]. The Equation (8)- (13) illustrate the linear relationship between these attributes and the moisture content (M):

$$\mathrm{L\ (mm)} = 0.0201\mathrm{M} + 9.6694;\ \mathrm{R}^2 = 0.9732 \tag{8}$$

$$\mathrm{W\ (mm)} = 0.007\mathrm{M} + 2.0015;\ \mathrm{R}^2 = 0.8704 \tag{9}$$

$$\mathrm{T\ (mm)} = 0.0065\mathrm{M} + 1.7669;\ \mathrm{R}^2 = 0.8944 \tag{10}$$

$$\mathrm{Da\ (mm)} = 0.0112\mathrm{M} + 4.4792;\ \mathrm{R}^2 = 0.9757 \tag{11}$$

$$\mathrm{De\ (mm)} = 0.0099\mathrm{M} + 3.2497;\ \mathrm{R}^2 = 0.9416 \tag{12}$$

$$\mathrm{Dg\ (mm)} = 0.0099\mathrm{M} + 3.2441;\ \mathrm{R}^2 = 0.9410 \tag{13}$$

Table 1 Dimensions of MR297 paddy at different moisture content levels.

Physical properties	Moisture content (%)				
	16.49	19.81	25.36	28.67	34.08
L (mm)	10.03±0.45^{c}	10.03±0.40^{c}	10.18±0.45^{bc}	10.25±0.44^{ab}	10.36±0.42^{a}
W (mm)	2.12±0.10^{b}	2.13±0.10^{b}	2.15±0.13^{b}	2.23±0.11^{a}	2.23±0.09^{a}
T (mm)	1.86±0.11^{c}	1.91±0.06^{b}	1.92±0.12^{b}	1.97±0.10^{a}	1.98±0.08^{a}
Da (mm)	4.67±0.18^{c}	4.69±0.14^{bc}	4.75±0.18^{b}	4.82±0.15^{a}	4.86±0.15^{a}
De (mm)	3.41±0.13^{c}	3.45±0.08^{bc}	3.48±0.13^{b}	3.56±0.11^{a}	3.58±0.10^{a}
Dg(mm)	3.41±0.13^{c}	3.44±0.08^{bc}	3.48±0.14^{b}	3.56±0.11^{a}	3.57±0.10^{a}

Values are presented as average ± standard deviation. Within the same column, the superscript letters ^{a},^{b}, and ^{c} represent a significant difference ($p < 0.05$).

3.2 Sphericity and aspect ratio

Table 2 illustrates the different aspect ratios and sphericity obtained with different moisture content levels ranging from 16.4% to 34.08%. These properties are important for the design of handling equipment and when rolling convenience is desired [25,32,33]. The aspect ratio of MR297 was considered lower than other varieties at around 0.3-0.55, which showed that the MR297 grains were long and slender [23]. Bold-shaped grains would have a higher aspect ratio value. The aspect ratio is the ratio between the major and minor axes. Within the examined moisture ranges, the aspect ratio of the rice ranged between 0.21 and 0.22. Similar trends were found in a previous study [7], which identified increases from 0.331 to 0.346 in the aspect ratio of milled grains of MR297 rice with increasing moisture content from 11.55% to 28.64%. There was only a slight difference in the aspect ratio. This means that not only was the growth in the major axis but also that there was a change in the cross direction.

Table 2 Shape of MR297 paddy at different moisture content levels.

Physical properties	Moisture content (%)				
	16.49	19.81	25.36	28.67	34.08
R_a (aspect ratio)	0.21±0.01^{b}	0.21±0.01^{b}	0.21±0.01^{ab}	0.22±0.01^{ab}	0.22±0.01^{a}
Sphericity	0.34±0.01^{c}	0.34±0.01^{bc}	0.34±0.01^{abc}	0.35±0.01^{ab}	0.35±0.01^{a}

The sphericity was calculated using the geometric mean diameter and the length of the main axis of paddy seeds (L). Table 2 illustrates the sphericity results. The sphericity decreased substantially from 0.35 to 0.34 (p <0.05) as the moisture content decreased. The smaller sphericity suggests that the paddy had a less spherical shape. Differences in the internal structure and composition of the grains may have accounted for the variations in the shape parameter changes with MC among the different grain types. As previously stated, the change in particle form is determined by dimensions that vary due to changes in moisture content. The slight variations in the sphericity of the rice indicated that the change in dimensions due to changes in water content occurred almost proportionally in three directions, with only a slightly larger change in one dimension. This resulted in the observation of a 1% variation in the shape characteristics between moisture content levels of 16.49% and 34.08%. The results are comparable to those of a previous study [7] in which an increase in moisture content from 11.55% to 26.84% led to an increase in sphericity from 0.45 to 0.460. Another researcher [22] also discovered a rise in sphericity from 0.367 to 0.377 as the moisture content rose from 8.40% to 28.28%. The Equation (14), (15) illustrate the linear relationships between both sphericity and the aspect ratio with the moisture content (M).

$$\mathrm{Ra} = 0.0003\mathrm{M} + 0.2076;\ \mathrm{R}^2 = 0.5150 \tag{14}$$

$$\mathrm{Sphericity} = 0.0003\mathrm{M} + 0.3360;\ \mathrm{R}^2 = 0.5487 \tag{15}$$

3.3 Surface area, volume, and thousand-grain mass

The relationships between the amount of moisture present and the surface area, volume, and mass per one thousand grains are depicted in Table 3. Significant changes occurred in the surface area, volume, and thousand-grain mass as a result of the changes in moisture content, which ranged from 16.49% to 34.08%. (p <0.05). It is essential to ascertain the surface area of grains and other particulate materials because this influences the rate of moisture loss during the drying process [20,21]. As the moisture percentage rose from 16.49% to 34.08%, there was a corresponding rise in the surface area, which increased from 34.81 to 38.04 mm^2. The relationship between the fluctuating amount of moisture and the surface area can be described quantitatively, as Equation (16) demonstrates. If the R^2 value is high, this means that the equation provides the best fit for the empirical data. Changes in the rice grain surface area that occurred in conjunction with an increase in the amount of moisture present may have resulted from the rice kernel expanding in all three dimensions as the moisture content rose. The same trend has been found in rice [8], doum palm fruits [19], green peas [6], soybean [18] and alfalfa seeds [12].

$$\mathrm{Surface\ area\ (mm2)} = 0.1957\mathrm{M} + 31.52;\ \mathrm{R}^2 = 0.9537 \tag{16}$$

The correspondence between the volume and moisture content of the rice kernels is presented in Table 3. The rice grain volume increased from 20.81 to 26.57 mm^3 (p <0.05) as moisture content rose from 16.49% to 34.08% (db). Similarly, another researcher reported an increase in the rice grain volume with increasing levels of moisture content [7]. This increase in volume might have been due to the increase in dimensions of the major, minor, and medium axes of the rice kernels. Rising levels of moisture content also increased the volume of doum palm fruits [19]. Equation (17) illustrates the linear governing relationship between the volume of the MR294 paddy grains and the percentage of moisture content.

$$\mathrm{Volume\ (mm3)} = 0.3523\mathrm{M} + 14.923;\ \mathrm{R}^2 = 0.9254 \tag{17}$$

The thousand-grain rice mass declined linearly from 35.375 to 31.554 g as the moisture content decreased from 34.08% to 16.49% w.b., as shown in Table 3. The relationship between the thousand-grain rice mass and the moisture content (M) was discovered to be linear, as described below in Equation (18).

The reported results confirmed the conclusions of the current study. The thousand-grain mass is a useful indicator of the "milling outturn," which is used to determine the amount of foreign or dockage material present in a particular lot of cereal grain as well as the proportion of immature and shriveled kernels [7]. These findings were in line with previous studies on green peas [6], maize [4,30], rice [4,7], and soybean [4,18]. Equation 18 illustrates the linear relationship that applies to the mass of 1000 grains and the amount of moisture present.

$$\mathrm{Thousand-grain\ mass\ (g)} = 0.234\mathrm{x} + 28.023;\ \mathrm{R}^2 = 0.9097 \tag{18}$$

Table 3 Surface area, volume, and thousand-grain mass of MR297 paddy at different moisture content levels.

Physical properties	Moisture content (%)				
	16.49	19.81	25.36	28.67	34.08
Surface area (mm^2)	34.81±2.63^c	35.35±1.72^{bc}	36.15±2.72^b	37.60±2.16^a	38.04±2.04^a
Volume (mm^3)	20.81±4.01^c	21.87±2.83^{bc}	23.08±4.17^b	26.12±4.10^a	26.57±3.80^a
Thousand-grain mass (g)	31.554	32.563	34.398	35.334	35.375

3.4 Correlation between the physical properties of MR297 paddy at different moisture content levels

Table 4 summarizes the Pearson correlation coefficients that were found between the various physical parameters of the MR297 paddy grains. There was a significant positive correlation between the moisture content of the paddy and the majority of the paddy's physical parameters (r = 0.718-0.988; p= 0.05). Since these parameters were related to the swelling of the paddy as the moisture content increased, it is possible to infer that the moisture content had strong associations with the length, width, thickness, arithmetic mean diameter, equivalent diameter, and geometrical mean diameter. This was deduced from the fact that the paddy expanded as the moisture content increased. The correlation study revealed no significant link (p>0.05) between the mean concentration (MC) and either the aspect ratio or sphericity of the grain. This suggested that there was no significant change in the form of the paddy as a result of the rise in moisture content. The study's findings further demonstrated that the shifts in the paddy dimensions were focused on the vertical and lateral dimensions of the paddy grains [7]. These changes in dimensions would change the overall physical properties and volumetric capacity of paddy grains in a storage or a processing chamber as the moisture content changed. Further work is required to investigate how the physical properties at different levels of moisture content influence the structural and morphological properties of the rice inside the paddy.

Table 4 Pearson correlation coefficients for physical properties of paddy.

	MC	L	W	T	Ra	Da	De	Dg	sphericity	SA	V	TKW
MC	1											
L	.986**	1										
W	.933*	.939*	1									
T	.946*	.904*	.953*	1								
Ra	0.718	0.712	.910*	0.858	1							
Da	.988**	.989**	.975**	.954*	0.800	1						
De	.970**	.960**	.989**	.980**	0.864	.991**	1					
Dg	.970**	.958*	.989**	.981**	0.865	.990**	1.000**	1				
Sphericity	0.741	0.686	0.870	.913*	.951*	0.787	0.862	0.866	1			
SA	.977**	.969**	.987**	.974**	0.849	.995**	.999**	.999**	0.844	1		
V	.962**	.954*	.993**	.978**	.879*	.988**	.999**	.999**	0.872	.998**	1	
TKW	.957*	.941*	.917*	.950*	0.742	.958*	.954*	.953*	0.776	.955*	.948*	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

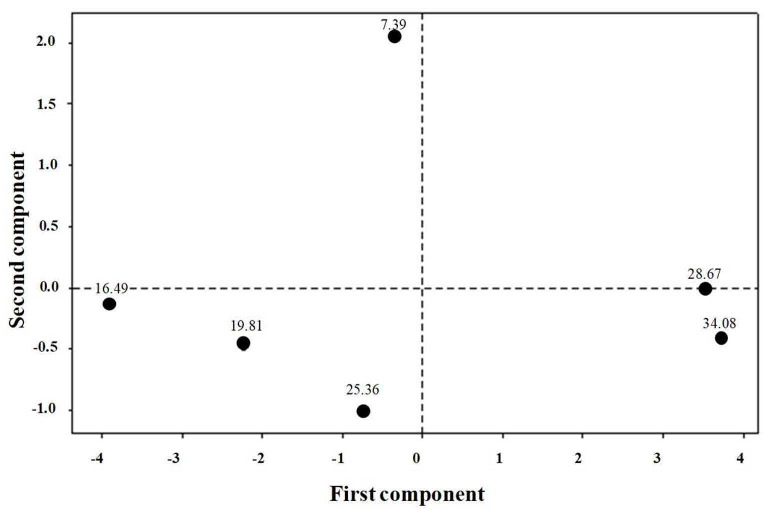

Figure 2 Score plot for PC1 and PC 2.

The score plot of the physical attributes of the MR297 paddy grains in various levels of moisture content is presented in Figure 2. It is based on the principal component analysis. The PCA score plot illustrates the differences in the physical attributes of the MR297 rice that occurred throughout the moisture content range. The first (PC1) and second (PC2) principal components (PC) accounted for 93.3% and 5.1%, respectively, of the variance, for a total of 98.4% (Table 5). The PC1 was the dominant component that delivered the information plotted in the PCA. Based on Table 6, all the physical properties were equally significant in PC1, but in PC2, the length, sphericity, and aspect ratio were the significant properties. Figure 2 also shows that the higher the moisture content, the more positively the sample load moved toward the PC1. This was also supported by the results described in a previous section, where in the Pearson correlation coefficients, all the R^2 values were positive. The intercepts of all the linear regression were also positive.

Table 5 Explained variance (Eigen analysis) of the correlation matrix.

Component	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Eigen value	10.267	0.564	0.132	0.037	0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000
Proportion	0.933	0.051	0.012	0.003	0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000
Cumulative	0.933	0.985	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 6 Correlation loadings for paddy at three different moisture content levels and 11 physical characteristics.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
L	0.295	0.419	0.237	0.113	-0.160	-0.214	-0.360	0.150	-0.604	0.209	0.188
W	0.309	-0.036	0.357	-0.125	-0.172	-0.286	0.148	-0.331	-0.054	-0.712	-0.086
T	0.307	-0.053	-0.451	0.340	-0.393	0.302	0.152	-0.017	-0.004	-0.200	0.525
Ra	0.276	-0.576	0.415	-0.412	-0.188	0.250	-0.054	0.150	0.017	0.263	0.238
Da	0.307	0.233	0.129	0.109	-0.004	0.436	-0.176	-0.659	0.193	0.276	-0.233
De	0.312	0.063	0.031	0.110	-0.087	0.074	0.723	0.241	-0.206	0.228	-0.445
Dg	0.312	0.055	0.022	0.160	-0.006	0.233	-0.419	0.559	0.316	-0.303	-0.373
Sphericity	0.276	-0.591	-0.373	0.229	0.146	-0.326	-0.253	-0.190	-0.250	0.108	-0.286
Surface area	0.311	0.107	0.068	0.133	-0.023	-0.581	0.089	0.042	0.619	0.305	0.215
V	0.312	0.027	0.079	0.051	0.852	0.148	0.137	0.046	-0.081	-0.126	0.320
TKW	0.297	0.257	-0.523	-0.751	0.014	-0.053	-0.042	-0.001	0.000	0.002	-0.056

4. Conclusion

The physical characteristics of MR297 paddy samples were examined in a range of moisture content levels from 16.49% to 34.08%. According to the findings, the amount of moisture present in paddy can impact its physical properties ($p < 0.05$). An increase in the moisture content will increase the dimensions (length, width, thickness, arithmetic mean diameter, and equivalent diameter), aspect ratio, sphericity, surface area, volume, and thousand-grain mass. The relationships between the moisture content and the physical characteristics were explained using linear equations. The model's highest coefficient determinant used the arithmetic mean diameter $R^2 = 0.9757$. The lowest coefficient determinant was the model using an aspect ratio with $R^2 = 0.5150$. This study will be beneficial for those designing and developing more effective sizing mechanisms and other types of post-harvest processing equipment.

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