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ORIGINAL ARTICLE

Evaluation of Physico-Mechanical Characteristics of Different Paddy Cultivars Grown in Humid Subtropical Region of Eastern China

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ABSTRACT

Background: Paddy during various stages *i.e.*, loading, transportation, storage, handling etc. occurs severe losses, which can be reduced by designing appropriate post-harvest machineries using physico-mechanical properties.

Objective: The study aimed to assess the variation in physico-mechanical properties of thirteen different paddy cultivars.

Methodology: The study was carried out at the College of Engineering, Nanjing Agricultural University, China. Thirteen different freshly harvested paddy cultivars were collected from Nanjing. Collected paddy cultivars before experiment were cleaned removing extraneous materials. Paddy cultivars were sealed in polythene bags, and were then kept in refrigerator at a temperature of 5ºC for 7 days for uniform distribution of moisture. The required amount of samples from each cultivar was accordingly taken for evaluating their physical and mechanical properties.

Results: The results when assessed were statistically different ($p \leq 0.05$) from each other. The average values of different paddy cultivars for length, width, thickness, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent diameter, surface area, volume, sphericity, aspect ratio, thousand kernel weight, bulk density, true density, porosity, hardness and toughness (for both horizontal and vertical orientations) were calculated to be 7.94mm, 3.32mm, 2.26mm, 3.84mm, 4.51mm, 2.56mm, 3.64mm, 46.53mm^2, 29.74mm^3, 0.49%, 0.42, 28.64 gm, 568.31 kg m^{-3}, 1225.20 kg m^{-3}, 54%, 46.09 N, 14.75 N, 16.06 mJ and 6.90 mJ respectively.

Conclusion: A wide variation was observed for each parameter while comparing different paddy cultivars. This wide variation in result will negatively affect the performance of the equipment and machinery being used for post-harvest practices. The study concludes that it is essential for industries involved in equipment design and machinery production, as well as end-users responsible for their implementation, to take into account these substantial differences among cultivars when making their decisions.

Keywords	*Address of Correspondence	Article info.
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INTRODUCTION

Rice as a dietary source of carbohydrates is consumed to meet required energy and nutrient intakes[1]. Rice among other cereals is one of the important crop on which Worlds populations rely on *i.e.*, consumed by 65% of Chinese peoples, staple food for more than 50% for Asia[2] and more than 60% for Worlds population[3]. Paddy globally production wise stands second with 740.9 metric tons from 154 million hectares, while first with 85% of human consumption when compared to wheat (72%) and maize (19%)[4] .China with 208 million tonnes is the World's largest producer and importer (2.2 million tonnes) of rice[5], it has further been reported that Jiangsu, Anhui, Hubei and Sichuan which are along Yangtze River Valley contributes to 49% of total rice production in China. Peng *et al.*[6] reported that despite this, to meet the needs of population the production has to be increased by 20%.

Rice marketing value as an agricultural product after its processing depends on its physical attributes, which is more favourable when achieved as a whole grain[7]. Rice leads to severe losses, depending on the intensity of the equipment's being used during different stages of processing[8]. Physical losses being occurred does not only makes the grain unsuitable for consumption but also reduces the economic value of crop[9]. Physical and mechanical properties has a core importance while storing, designing, dimensioning and manufacturing the equipment's being used during processing[10]. Dimensional properties, mass, volume and surface area are considered to be the most important parameters in grading systems, which also decreases the packaging and transportation costs[11]. The clearance between the cylinder and the concave of a combine harvester also relies on the size and dimension of grain[12]. Correa *et al.*[13] while studying drying and storage, considered moisture content, volume and porosity as basic parameters. Hardness is one of the most important quality parameters, which can reduce breakage, while improving the consumer acceptability of particular rice cultivar[14]. Mechanical shear resistance of grains is an important issue of concern to the designers and researchers associated with the design of machinery used for threshing, handling and processing.[15]. Knowledge of physical and mechanical properties is reported to be important when designing appropriate machinery for operations such as harvesting, sorting, drying, grinding, heating, cooling and milling[16], whereas efforts are still being taken to maintain the quality of crop when undergoing different processing operations.

Rice cultivars in order to maintain/control the quality of rice should categorically be simplified, which in an industrial point of view has a realistic approach. The objective of this study was therefore carried out to evaluate the physical and mechanical characteristic of thirteen different paddy cultivars grown in humid subtropical region of Eastern China.

MATERIALS AND METHODS

Experimental Site and Sample Preparation

The current research was carried out at the College of Engineering, Nanjing Agricultural University, China. Thirteen different freshly harvested paddy cultivars (Table **1**) were collected from Jiangpu, Nanjing of Jiangsu Province. Collected paddy cultivars before experiment were cleaned removing extraneous materials. Initial moisture of paddy cultivars was calculated by keeping the samples of paddy cultivars in the oven at a temperature of 105 ºC for 24 hours[13]. Paddy cultivars in different polythene bags were tightly sealed, which were then kept in refrigerator at a temperature of 5 ºC for 7 days for uniform distribution of moisture[17]. The required amount of samples from each cultivar was accordingly taken for evaluating their physical and mechanical properties.

Table 1. Selected paddy cultivars.

Sr. No	Paddy Cultivar	Symbol
1	Ma Lai Hong	VR 01
2	Jing Hui 1229	VR 02
3	Zhong Li Jing Dao1	VR 03
4	Zhong Li Jing Dao 2	VR 04
5	Bing Bao 1033	VR 05
6	Bing Bao 1286	VR 06
7	Bing Bao 1315	VR 07
8	Kuai Guan Jing Hui	VR 08
9	Nan Tuo Jing	VR 09
10	Hong Ke Jing Dao	VR 10
11	Hua Ke Chang Li Jing	VR 11
12	Zi Jian Jing Hui	VR 12
13	Zi Jian Jing	VR 13

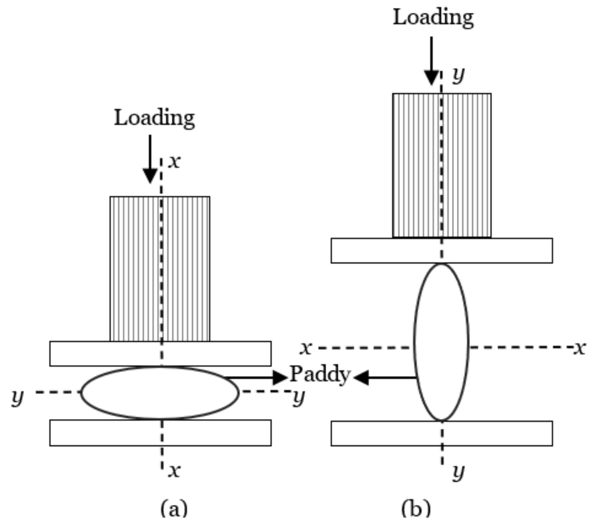

Figure 1. Orientation of paddy cultivar (a-horizontal and b-vertical) under compressive load.

Physical and Mechanical Properties

For determining three linear dimensions of paddy grain *i.e.*, length (L), width (W) and thickness (T), 100 grain samples from each cultivar were randomly selected which were then carefully measured using digital Vernier calliper having an accuracy of 0.01 mm. Geometric mean diameter (Dg), arithmetic mean diameter (Da), square mean diameter (Ds), equivalent diameter (De), surface area (S), volume (V), sphericity (φ) and aspect ratio (Ra) were calculated using principle values of three linear dimensions of paddy[18-20]. Hundred grains from each cultivar were randomly selected and weighed, for thousand kernel they were then multiplied by ten[21]. Bulk density (D_b) of cultivar was determined by dividing the mass of grains by volume of the container, the grains were filled in a container of known volume, whereas the mass added was weighed using electronic weight balance[22]. True density (D_t) of paddy cultivars was obtained by dividing the mass of the sample to its volume adopting water displacement method[23]. Porosity (Ɛ) was calculated using the valuess of bulk and true densities (Eq. 1) which is termed to be the ratio of intergranular void space volume and the volume of the bulk grain.

$$\varepsilon = \left(\frac{D_t - D_b}{D_t}\right) \times 100 \qquad \text{..... Eq. 1}$$

Compression tests were performed using TMS-Pro machine (FTC Co. USA). The measurement accuracy of TMS-Pro machine was ± 0.001 N in force and 0.001 mm in deformation[24]. Ten random grains were randomly selected and tested for compression for each cultivar. Effect of orientation by loading was also determined, selected grain for horizontal position as shown in Figure **1a** was placed with major axis normal to the direction of loading, whereas when positioned vertically as shown in Figure **1b** the major axis was parallel to the direction of loading. The toughness which is termed as the energy causing rupture under compression was determined by calculating the area under force deformation curve until grain rupture.

Experimental Design and Data Analysis

Statistical software Statistix (Ver. 8.1) was used for statistically analyzing the data at the significance level of $p \leq 0.05$, whereas Tukey's multiple range test was used to separate means. OriginPro 2016 was used for graphical representation.

RESULTS AND DISCUSSION

A summary of dimensional properties of different paddy cultivars is presented in Table **2**, and correlated in Table **3**. The paddy cultivars when compared were significantly different ($p \leq 0.05$) from each other. Among cultivars the length of paddy varied from 6.98 (VR 06) to 8.79 mm (VR 13), width of paddy varied from 2.79 (VR 01) to 3.70 mm (VR 06), thickness of paddy varied from 2.01 (VR 13) to 2.52 mm (VR 09), geometric mean diameter of paddy varied from 3.61 (VR 01) to 4.07 mm (VR 09), arithmetic mean diameter of paddy varied from 4.32 (VR 06) to 4.67 mm (VR 12), square mean diameter of paddy varied from 2.48 (VR 01) to 2.63 mm (VR 09), equivalent diameter of paddy varied from 3.50 (VR 01) to 3.76 mm (VR 09), surface area of paddy varied from 41.01 (VR 01) to 52.00 (VR 09) mm^2, volume of paddy varied from 24.56 (VR 01) to 35.05 (VR 09) mm^3, sphericity of paddy varied from 0.42 (VR 13) to 0.55 % (VR 06) and aspect ratio of paddy varied from 0.32 (VR 13) to 0.53 (VR 06). Value of rice as an agricultural product in market after harvesting depends on its physical properties[25]. Wide differences in dimensions of grain has been reported while dealing with different rice varieties[13,19]. For effective implementation of equipment's for different operations, information of dimensional properties is necessarily to be collected[26]. Varnamkhasti *et al*.[27] stated that, axial dimensions are important to be considered when designing and selecting the sieve separators, they further reported that aspect ratio distribution of grains is necessarily to be obtained for its classification and determining the range of off-size in market grade. Surface to volume ratio can be used to characterize the effects of drying of particulate materials, which in result also affects the drying time and energy being consumed[8].

Table 2. Dimensional properties of paddy cultivars.

Variety	L (mm)	W (mm)	T (mm)	Dg (mm)	Da (mm)	Ds (mm)	De (mm)	S (mm^2)	V (mm^3)	φ (%)	Ra
VR 01	8.37^{c}	2.79^{i}	2.10^{h}	3.61^{h}	4.42^{f}	2.48^{i}	3.50^{g}	41.01^{h}	24.56^{g}	0.43^{j}	0.33^{k}
VR 02	8.52^{b}	3.22^{f}	2.29^{de}	3.91^{c}	4.67^{a}	2.60^{bc}	3.73^{b}	48.15^{c}	31.31^{c}	0.46^{h}	0.38^{i}
VR 03	7.49^{f}	3.49^{c}	2.39^{c}	3.91^{c}	4.46^{e}	2.57^{def}	3.65^{de}	48.10^{c}	31.19^{c}	0.52^{c}	0.47^{d}
VR 04	7.63^{e}	3.45^{d}	2.30^{d}	3.87^{de}	4.46^{e}	2.56^{f}	3.63^{e}	46.96^{de}	30.11^{d}	0.51^{d}	0.45^{e}
VR 05	7.75^{d}	3.35^{e}	2.30^{d}	3.85^{ef}	4.46^{e}	2.55^{f}	3.62^{e}	46.59^{ef}	29.75^{de}	0.50^{e}	0.43^{g}
VR 06	6.98^{h}	3.70^{a}	2.27^{de}	3.83^{f}	4.32^{g}	2.53^{g}	3.56^{f}	46.15^{f}	29.32^{e}	0.55^{a}	0.53^{a}
VR 07	7.82^{d}	3.44^{d}	2.24^{f}	3.86^{de}	4.50^{d}	2.56^{ef}	3.64^{de}	46.87^{de}	30.00^{d}	0.49^{e}	0.44^{f}
VR 08	7.31^{g}	3.61^{b}	2.44^{b}	3.95^{b}	4.45^{e}	2.58^{cde}	3.66^{cd}	49.04^{b}	32.11^{b}	0.54^{b}	0.48^{b}
VR 09	7.58^{e}	3.68^{a}	2.52^{a}	4.07^{a}	4.59^{b}	2.63^{a}	3.76^{a}	52.00^{a}	35.05^{a}	0.54^{b}	0.49^{c}
VR 10	8.30^{c}	3.37^{e}	2.17^{g}	3.88^{d}	4.61^{b}	$2.58c^{d}$	3.69^{c}	47.19^{d}	30.31^{d}	0.47^{g}	0.41^{h}
VR 11	8.35^{c}	2.90^{g}	2.11^{h}	3.66^{g}	4.45^{e}	2.50^{h}	3.54^{f}	42.11^{g}	25.56^{f}	0.44^{i}	0.35^{j}
VR 12	8.34^{c}	3.41^{d}	2.26^{e}	3.95^{b}	4.67^{a}	2.61^{b}	3.74^{ab}	49.04^{b}	32.12^{b}	0.47^{f}	0.41^{h}
VR 13	8.79^{a}	2.85^{h}	2.01^{i}	3.64^{g}	4.55^{c}	2.50^{h}	3.57^{f}	41.72^{g}	25.21^{f}	0.42^{k}	0.32^{l}

Mean of 100 samples.

Resources followed by superscript letters in a column are significantly different from others.

Table 3. Correlation of dimensional properties of different paddy cultivars.

	L	W	T	Dg	Da	Ds	De	S	V	φ
W	-0.82	-	-	-	-	-	-	-	-	-
T	-0.71	0.84	-	-	-	-	-	-	-	-
Dg	-0.50	0.87	0.89	-	-	-	-	-	-	-
Da	0.60	-0.06	0.04	0.39	-	-	-	-	-	-
Ds	-0.25	0.73	0.75	0.96	0.62	-	-	-	-	-
De	-0.06	0.59	0.65	0.89	0.76	1.00	-	-	-	-
S	-0.49	0.86	0.89	1.00	0.39	0.96	0.90	-	-	-
V	-0.49	0.86	0.89	1.00	0.40	0.96	0.90	1.00	-	-
φ	-0.95	0.94	0.86	0.73	-0.33	0.52	0.36	0.73	0.72	-
Ra	-0.93	0.96	0.80	0.73	-0.31	0.53	0.37	0.73	0.72	0.98

Thousand kernel weight of paddy cultivars were observed to be significantly different ($p \leq 0.05$). Thousand kernel weight of paddy cultivars varied from 23.52 (VR 01) to 35.06 g (VR 09) as shown in Figure **2a**, having a difference of 11.54 gm. The average thousand kernel weight of cultivars was calculated to be 28.54 gm. Similar results for thousand kernel weight has also been reported by Mir *et al*.[28] and Ozguven & Vursavus[29]. Comparing thousand kernel weight of the paddy is useful for milling outturn, measuring relative amount of dockage and shriveled kernels[30]. Bulk density of paddy cultivars when compared were statistically different ($p \leq 0.05$) from each other as shown in Figure **2b**. Bulk density of paddy cultivars varied from 493.15 (VR 05) to 640.80 kg m^{-3} (VR 10), with an average value of 568.51 kg m^{-3}. The variation here in bulk density may relate to the grain shape, which differed for different cultivars (Table **2**). For bulk density, Muramatsu *et al*.[31] have reported similar findings for different regions. Properties including bulk density affects the quality of grain, which in result are necessary to be calculated[32], where Nalladulai *et al*.[33] implied necessity of knowing bulk density when designing silos and hoppers for handling and storage of grain.

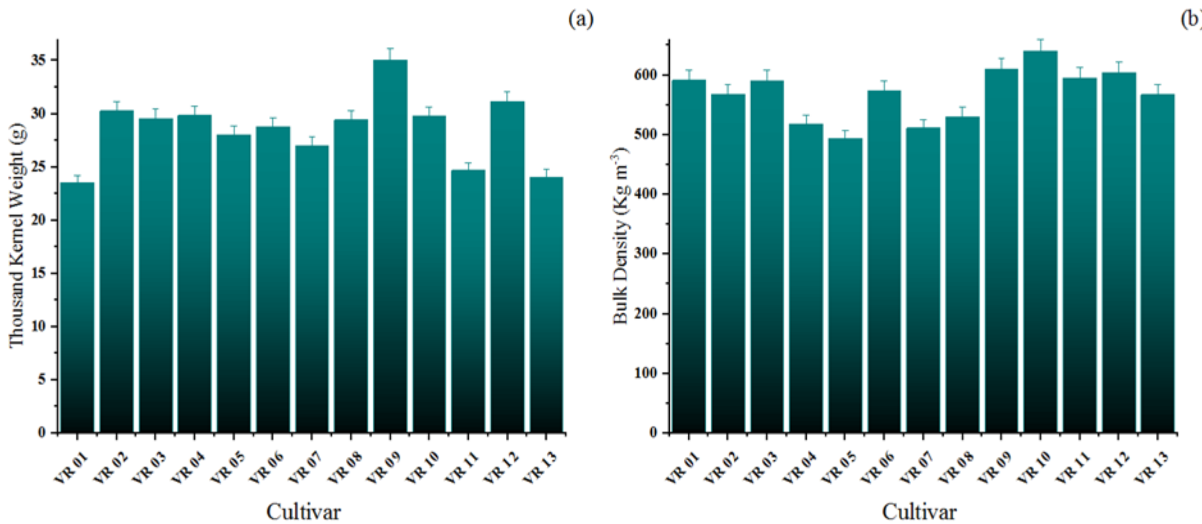

Figure 2. Thousand kernel weight (a) and bulk density (b) of different paddy cultivars.

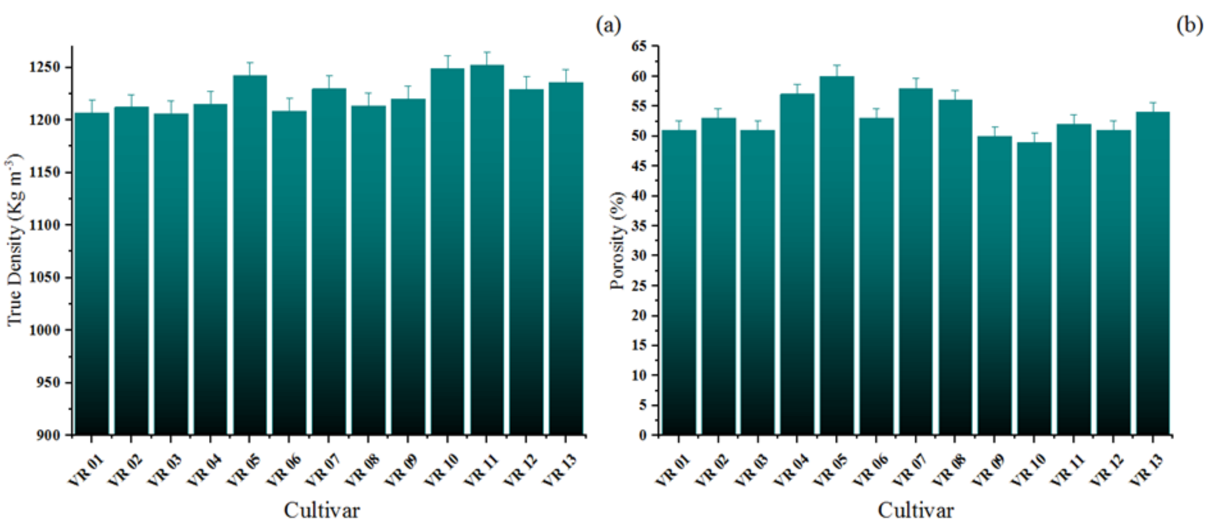

Figure 3. True density (a) and porosity (b) of different paddy cultivars.

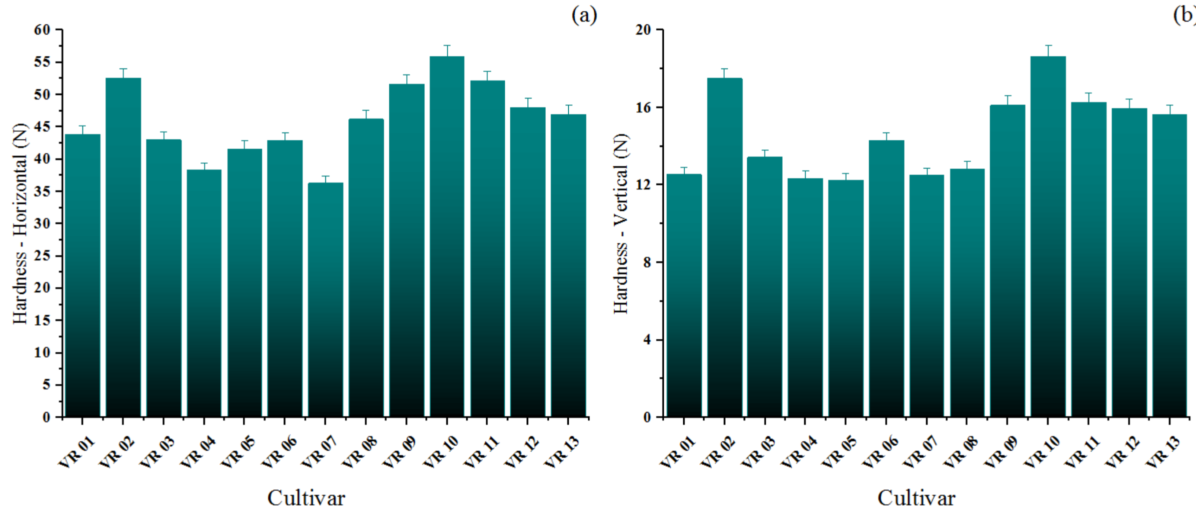

Figure 4. Hardness at horizontal (a) and vertical (b) orientations of different paddy cultivars.

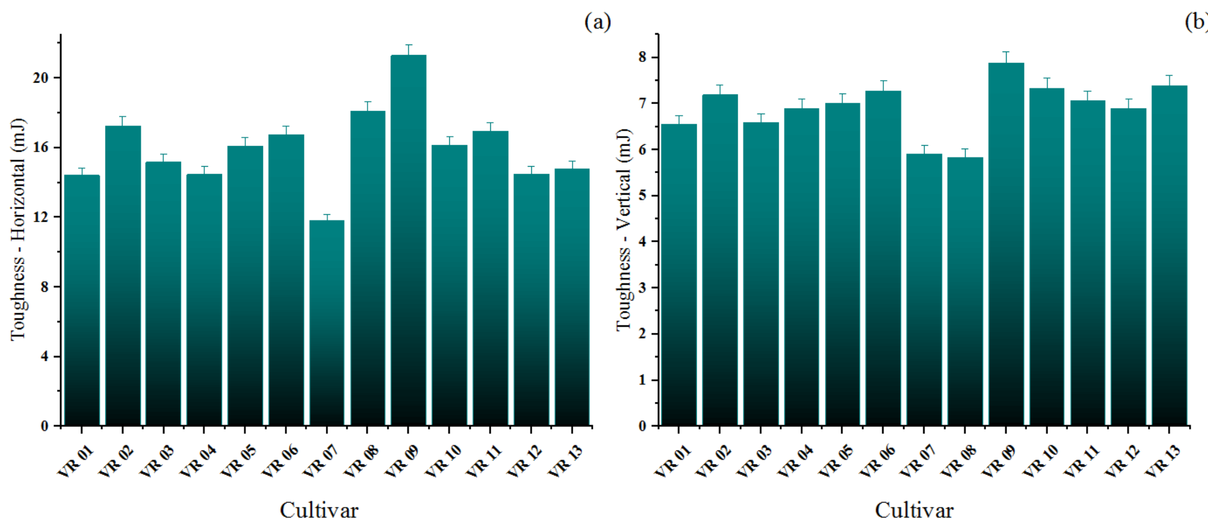

Figure 5. Toughness at horizontal (a) and vertical (b) orientations of different paddy cultivars.

True density for different paddy cultivars were observed to be statistically ($p \leq 0.05$) different from each other (Figure **3a**). True density of paddy varied from 1206.23 (VR 03) to 1251.88 kg m^{-3} (VR 11). The average value for paddy cultivars was 1224.60 kg m^{-3} with a difference of 45.65 kg m^{-3}. Similar significant results has also been reported by Brooker *et al.*[34] and Mir *et al.*[28]. Determination of such property during aeration and drying are necessarily to be determined which affects the transfer rate of heat and mass[35]. Porosity which was calculated by values of bulk and true densities (Eq. 1) were also statistically different ($p \leq 0.05$). Porosity of paddy cultivars as shown in Figure **3b** varied from 49 (VR 10) to 60% (VR 05). The average value of cultivars was calculated to be 54%, having a difference of 11%. Similar results for porosity has also been stated by Correa *et al.*[13]. Measuring porosity which within other properties has importance while studying heat and mass transfer and movement of air through the bulk grain[36].

Hardness for both orientations *i.e.*, horizontally and vertically when tested were statistically different from each other ($p \leq 0.05$). Hardness for horizontal orientation varied from 36.27 (VR 07) to 55.92 (VR 10) N, with an average value of 46.09 N (Figure **4a**), for vertical orientation the hardness varied from 12.24 (VR 05) to 18.64 (VR 10) N with an average value of 14.75 N (Figure **4b**). Toughness at horizontal orientation for different varieties when tested was significantly different ($p \leq 0.05$), whereas for vertical orientation it was observed to be non-significant. Toughness for horizontal orientation varied from 11.82 (VR 07) to 21.30 (VR 09) mJ, having an average of 16.06 mJ (Figure **5a**). Toughness for vertical orientation varied from 5.85 (VR 08) to 7.89 (VR 09) mJ, having an average of 6.90 mJ (Figure **5b**). Milling yield, which is considered to be one of the important parameter while processing can be maximized by determining hardness[28]. The values for both hardness and toughness were greater for paddy cultivars kept in horizontal orientation, the results are in line with the findings of Correa *et al.*[13]; Zareiforoush *et al.*[37] and Putri *et al.*[38], whom also reported same while working with different varieties of rice.

Practices applied on post-harvest operations on crops leads to a loss of about 10 – 20% in developed, and about 25 – 40% in developing countries throughout the supply chain. The loss in rice being occurred is mainly assorted with socioeconomic development, adoption of proper method of production, harvesting, transporting, milling and storing of crops. Lack or improper handling of any practice will effectively result a loss, reducing the profit of farmers along with affecting the supply-demand of crops being required. Rise in rice production by huge investment is important to fulfill the supply demand, which on other hand has great losses too, where a step taken ahead to reduce post-harvest losses can not only save cost, but can increase total turnout reducing losses and improving the quality of paddy.

CONCLUSION

The study concluded with significant results for physico-mechanical properties when observed for thirteen different paddy cultivars grown in humid subtropical region of Eastern China. A wide variation for length, width, thickness, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent diameter, surface area, volume, sphericity, aspect ratio, thousand kernel weight, bulk density, true density, porosity, hardness and toughness was found between selected paddy cultivars. Proper utilization of these observations while designing related equipment's and machineries is necessary, which reduces the losses being occurred during post-harvest practices. As the land for cultivating rice in China is limited, hence adoption of efficient post-harvest operations can be one of the solutions which could meet the required demands, providing new classification of paddy cultivars.

CONTRIBUTOR STATEMENT

Shakeel Ahmed Soomro and Kunjie Chen contributed in study conception and design. Shakeel Ahmed Soomro and Fangfang Ji contributed in performing the experiments. Shakeel Hussain Chattha and Salahuddin Soomro contributed in analysis of data. Bakhtawar Wagan, Farman Ali Chandio and Aamir Lund contributed in interpretation of data. Shakeel Ahmed Soomro and Sohail Ahmed Soomro contributed in writing the manuscript.

CONFLICT OF INTEREST

The authors have declared no conflict of interest

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LIST OF ABBREVIATION

None

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