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# Effect of Moisture Content on Some Physical Properties of Paddy Grains

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**Abstract:** The moisture-dependent physical properties of agricultural grains are important to design post harvest equipments of the product. In the current study, various physical properties of two different paddy cultivars were determined at five moisture content levels of 8, 11, 14, 18 and 21% (d.b.). In the case of Alikazemi cultivar, the average length, width, thickness, equivalent diameter, surface area, volume, sphericity, thousand grain mass and angle of repose increased from 9.83 to 10.05 mm, 2.65 to 2.76 mm, 1.92 to 2.01 mm, 3.72 to 3.85 mm, 39.37 to 42.12 $mm^2$, 26.91 to 29.94 $mm^3$, 37.51 to 38.04%, 27.63 to 31.20 g and 35.67º to 41.23º, respectively, as the moisture content increased from 8 to 21% (d.b.). The corresponding values increased from 10.20 to 10.25 mm, 2.31 to 2.40 mm, 1.85 to 1.92 mm, 3.53 to 3.63 mm, 36.87 to 38.61 $mm^2$, 23.12 to 25.11 $mm^3$, 34.53 to 35.27%, 24.43 to 27.80 g and 38.27º to 44.37º, respectively, for Hashemi cultivar. For Alikazemi cultivar, the static coefficient of friction of grains increased linearly against three various surfaces, namely, glass (0.3168-0.4369), galvanized iron sheet (0.4179-0.4965), and plywood (0.4394-0.5264) as the moisture content increased from 8 to 21% (d.b.). The corresponding value for Hashemi cultivar increased from 0.3577 to 0.4650, 0.4629 to 0.5082 and 0.4857 to 0.5452, respectively, against three mentioned surfaces.

**Key words:** Agricultural equipment, moisture content, paddy grain, physical properties and variety

## INTRODUCTION

Rice (*Oryza Sativa* L.) is among the oldest of cultivated crops and ranks as the most widely grown food grain crop, serving as the staple food for about half the world's population. World rice production increased from 520 million ton in 1990 to 658 million ton in 2007 (FAOSTAT, 2007). In Iran, rice is grown on an area of about 615000 ha with a total paddy production of about 3.0 million ton. Main areas of rice cultivation in Iran are located in Mazandaran and Guilan provinces producing 75 percent of Iran's rice crop. In Guilan province however, the most popular varieties grown are local and aromatic varieties such as Alikazemi and Hashemi. These varieties are characterized by long kernels having awns (Fig. 1). The presence of awn influences the physical and morphological characteristics of these types of rice varieties that cause difficulty in flow through chutes and hopper orifices (Alizadeh *et al.*, 2006).

Physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behavior of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in these processes involve knowledge of their physical and engineering properties (Irtawange, 2000). 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. Thousand grain mass of paddy grain is used for calculating the head rice yield (HRY is the mass percentage of paddy that remains as head rice). Head rice is 3/4 or more of the whole milled kernels separated from the total milled rice (USDA, 1990). Data on actual milling output are obtained from the millers and are expressed in percentage of paddy fed for milling. Expected milling output is determined at the laboratory by taking the weight of a thousand grains of milled head rice and the corresponding weight of a thousand grains of paddy and then expressing the weight of milled head rice as a percentage of the weight of the paddy. Any short fall in actual milling output was

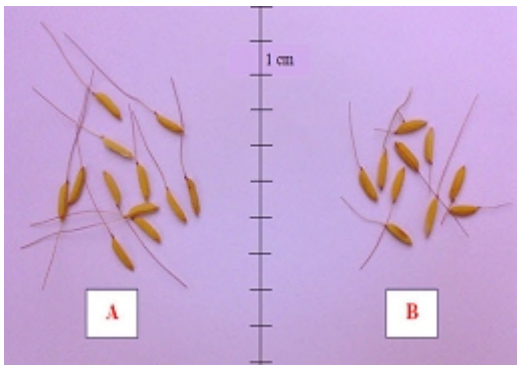


Fig 1: Paddy grains: A, Hashemi variety; B, Alikazemi variety

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considered as the milling loss due to breakage of grain (Sarker and Farouk, 1989).

Bulk density, true density, and porosity (the ratio of inter granular space to the total space occupied by the grain) can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies (Ghasemi Varnamkhasti *et al*., 2007).

Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper wall's inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by gravity. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi varnamkhasti *et al*., 2007). The knowledge of physical properties of rice such as dimension characteristics and determination of milled rice quality parameters by image processing techniques will enable regular monitoring of milling operation in an objective manner, and thus allow the operator to quickly react within a few minutes to changes in material properties (Yadav and Jindal, 2001).

Since grain property variation is wide, especially when considering variety difference, rice cannot be considered to have uniform properties. Moreover, the moisture content of paddy grain decreases from 22 to 8%, during harvesting to milling projects. Differences in grain moisture content can result in a significant variation in the processing characteristics of the grain. Hence, the objective of this study was to determine some physical properties of two varieties of paddy, Alikazemi and Hashemi, as a function of moisture content in the range of 8 to 21% (d.b.) which can help out in the design of handling, threshing, de-husking and milling equipment for rice production.

## MATERIALS AND METHODS

The paddy cultivars, Alikazemi and Hashemi, used for this study was obtained from the Rice Research Institute, Rasht, Iran. The varieties used in the current study were two popular rice varieties in north of Iran. The samples were manually cleaned to remove all foreign materials such as dust, dirt, small broken and immature kernels. The initial moisture content of the samples was determined by oven drying method at 103ºC for 48 h (Sacilik *et al*., 2003). The initial moisture contents of grains were 14.6 and 14.8% (d.b.) for Alikazemi and Hashemi cultivars, respectively.

Samples that their moisture content should be raised were moistened with a calculated quantity of distilled water by using the following Eq. (1) and conditioned to raise their moisture content to the desired two different levels (Coşkun *et al*., 2005):

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \tag{1}$$

where $Q$ is the mass of added water (kg), $W_i$ is the initial mass of the sample (kg), $M_i$ is the initial moisture content of the sample (%, d.b.) and $M_f$ is the final moisture content of the sample (%, d.b.).

In order to obtain three desired moisture levels below the initial moisture contents, the samples were kept in an oven at a constant temperature of 43 ˚C until the desired moisture contents of the samples were obtained (Yang *et al*., 2003).

After making five levels of moisture contents, for both the selected cultivars, the samples were poured in polyethylene bags and the bags sealed tightly. The samples were kept at 5 ºC in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Before starting of each test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h. The rewetting technique to attain the desired moisture content in kernel and grain has frequently been used (Coşkun *et al*., 2005; Garnayak *et al*., 2008; Pradhan *et al*., 2008). All the physical properties of the grains were determined at moisture levels of 8, 11, 14, 18 and 21 % (d.b.) for both the Alikazemi and Hashemi cultivars. Ten replications of each test were made at each moisture content level.

The length, width, thickness and mass of paddy grains were measured in randomly selected 100 paddy grains. The length, width and thickness of grains were measured using vernier calipers to an accuracy of 0.01 mm.

The thousand grain mass was determined by means of a digital electronic balance having an accuracy of 0.00 g. To evaluate the thousand grain mass, 100 randomly selected grains from the bulk sample were averaged.

The equivalent diameter ($D_p$) in mm considering a prolate spheroid shape for a paddy grain, was calculated using (Mohsenin, 1986):

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

Grain volume ($V$) was calculated using (Jain and Bal, 1997):

$$V = 0.25\left[ (\frac{\pi}{6}) L?(W+T)^2 \right] \tag{3}$$

Grain surface area ($S$) was calculated using (Jain and Bal, 1997):

$$S = \frac{\pi B L^2}{2L - B} \quad (4)$$

where:

$$B = \sqrt{WT} \quad (5)$$

The sphericity (ø) defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain was determined using (Mohsenin, 1986):

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

where $L$ is the length, $W$ is the width and $T$ is the thickness of grain, all in mm.

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the apparatus (Fig. 2) consisting of an adjustable plywood box of 140×160×35mm and an electrical motor to lifting the box. The adjustable box was filled with the sample, and then was inclined gradually by the electrical motor allowing the grains to follow and assume a natural slope; this was measured as emptying angle of repose. A similar trend has been done by Tabatabaeefar (2003).

The bulk density was determined by filling a cylindrical container of 500 ml volume with the grains a height of 150 mm at a constant rate and then weighing the contents (Garnayak *et al*., 2008; Pradhan *et al*., 2008). No separate manual compaction of kernels was done. The bulk density was calculated from the mass of the kernels and the volume of the container. The true density defined as the ratio between the mass of paddy grains and the true volume of the grains, was determined using the toluene ($C_7H_8$) displacement method. Toluene was used instead of water because it is absorbed by kernels to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of paddy grains in the measured toluene (Garnayak *et al*., 2008).

The porosity was calculated from bulk and true densities using the relationship (Jain and Bal, 1997) as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (7)$$

where $\epsilon$ is the porosity (%), $\rho_b$ is the bulk density (kg/m$^3$) and $\rho_t$ is the true density (kg/m$^3$).

The static coefficient of friction of paddy grains against three different surfaces, namely, glass, galvanized iron sheet and plywood was determined using a cylinder of diameter 75mm and depth 50mm filled with grains.

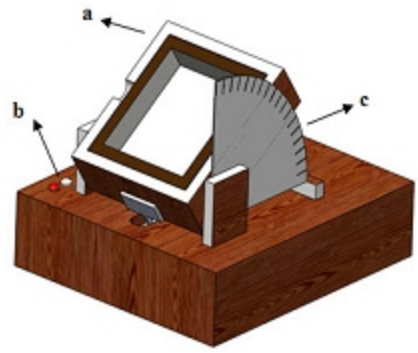


Fig 2: Apparatus for measuring emptying angle of repose: a, adjustable box; b, electrical key; c, gauge.

With the cylinder resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006; Ghasemi varnamkhasti *et al*., 2007). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan\alpha \quad (8)$$

where $\mu$ is the coefficient of friction and $\alpha$ is the angle of tilt in degrees.

The data were analyzed statistically using SPSS 13 software and analysis of regression using Microsoft Excel software.

## RESULTS AND DISCUSSION

**Grain Dimensions:** Average values of the three principal dimensions of paddy grains at different moisture contents are presented in Table 1. As it can be seen, for both the evaluated cultivars, upon moisture absorption, the paddy grain expands in length, width and thickness within the moisture range of 8 to 21% (d.b.). In the case of Alikazemi cultivar, the average length, width and thickness of the 100 grains increased from 9.83 to 10.05 mm ($P < 0.05$), 2.65 to 2.76 mm ($P < 0.01$) and 1.92 to 2.01 mm ($P < 0.01$), respectively; While the corresponding values for Hashemi cultivar increased from 10.20 to 10.25 mm ($P > 0.05$), 2.31 to 2.40 mm ($P < 0.01$) and 1.85 to 1.92 mm ($P < 0.01$), respectively, as the moisture content increased from 8 to 21% (d.b.). The results also showed that the width and thickness of the Alikazemi cultivar was greater than those of the Hashemi cultivar, but the Hashemi cultivar represented higher length than the Alikazemi cultivar at all moisture content levels.

**Equivalent Diameter:** The equivalent diameter of the paddy cultivars was calculated by using Eq. (2). As shown in Fig. 3, for both the evaluated cultivars in this study, the equivalent diameter of paddy grain increased linearly with

Table 1: Principal dimensions of paddy grain varieties at different moisture contents

| Variety | Alikazemi | | | Hashemi | | |
|---|---|---|---|---|---|---|
| Moisture content, (%, d.b.) | Principal dimensions (mm) | | | | | |
| | Length | Width | Thickness | Length | Width | Thickness |
| 8 | 9.83 (0.34) a | 2.65 (0.08) a | 1.92 (0.04) a | 10.20 (0.43) a | 2.31 (0.05) a | 1.85 (0.03) a |
| 11 | 9.85 (0.39) a | 2.67 (0.08) bc | 1.94 (0.04) b | 10.21 (0.44) a | 2.32 (0.05) ab | 1.86 (0.02) ab |
| 14 | 9.88 (0.41) a | 2.69 (0.07) c | 1.96 (0.03) c | 10.22 (0.37) a | 2.36 (0.08) bc | 1.87 (0.02) b |
| 18 | 9.96 (0.45) ab | 2.73 (0.07) d | 1.99 (0.03) d | 10.23 (0.37) a | 2.38 (0.17) cd | 1.89 (0.04) c |
| 21 | 10.05 (0.42) a | 2.76 (0.06) e | 2.01 (0.03) e | 10.25 (0.42) a | 2.40 (0.17) d | 1.92 (0.05) d |

Figures in parenthesis are standard deviation. Values in the same columns followed by different letters (a–d) are significant ($P < 0.05$).

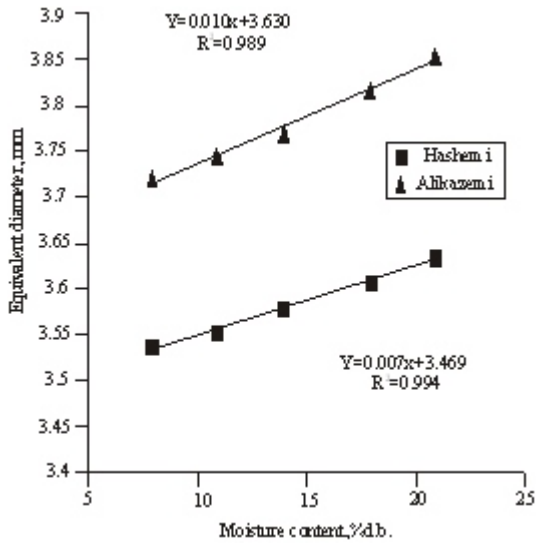


Fig 3: Effect of moisture content on equivalent diameter of paddy grain.

increasing moisture content. The equivalent diameter of paddy grain increased significantly ($P < 0.01$) from 3.72 to 3.85 mm and 3.53 to 3.63 mm, for Alikazemi and Hashemi varieties, respectively, when the moisture content increased from 8 to 21% (d.b.). The results also indicated that the equivalent diameter of the Alikazemi cultivar was greater than that of the Hashemi cultivar at all moisture content levels.

**Grain Volume:** The variation of volume with moisture content for both varieties of paddy grains is shown in Fig. 4. The volume of both varieties of paddy grains was observed to increase linearly from 26.91 to 29.94 $mm^3$ ($P < 0.01$) and 23.12 to 25.11 $mm^3$ ($P < 0.01$) for Alikazemi and Hashemi varieties, respectively, when the moisture content increased from 8 to 21% (d.b.). It can be seen from Fig. 4 that the grain volume of the Alikazemi variety was higher than that of the Hashemi variety at all moisture content levels. Baümler *et al.* (2006) also reported that the volume of safflower seeds respectively increased linearly with increasing moisture content.

**Surface Area:** The surface area of the paddy grain was calculated by using Eq. (4). As seen from the Fig. 5, the surface area of paddy grain increased linearly from 39.37 to 42.12 $mm^2$ ($P<0.01$) and 36.87 to 39.16 $mm^2$ ($P<0.01$),

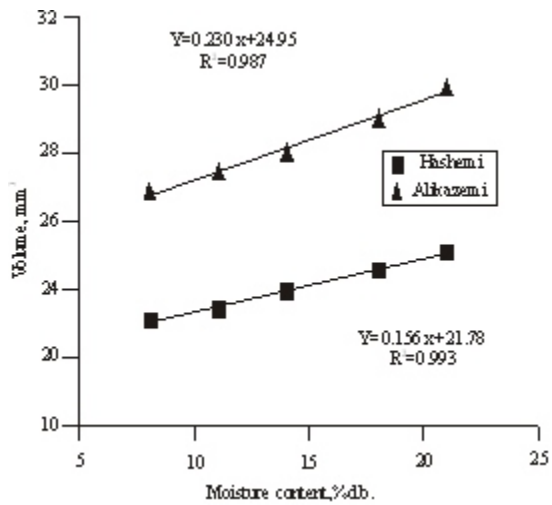


Fig 4: Effect of moisture content on grain volume of paddy cultivars

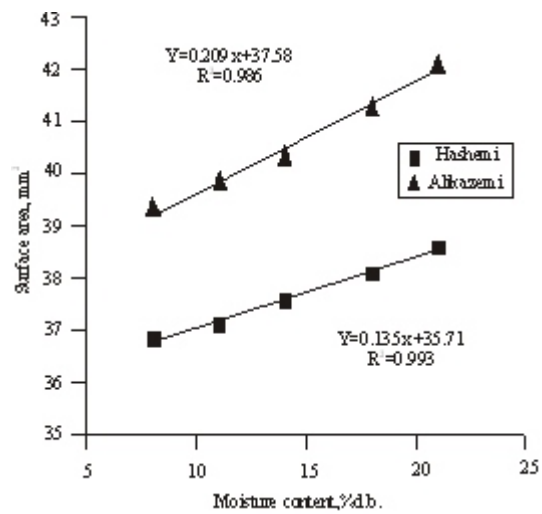


Fig 5: Effect of moisture content on surface area of paddy grain.

respectively, for Alikazemi and Hashemi cultivars, when the moisture content increased from 8 to 21% (d.b.). The presented results in the Fig. 5 also show that for Alikazemi cultivar, the surface area is greater than that of the Hashemi cultivar at all moisture content levels. A similar trend has been reported by Altuntaş *et al.* (2005) for fenugreek seeds, Selvi *et al.* (2006) for linseed and Pradhan *et al.* (2008) for karanja kernel.

**Sphericity:** The values of sphericity were calculated individually with Eq. (6) by using the data on geometric mean diameter and the major axis of the grain and the results obtained are presented in Fig. 6. This figure indicates that the sphericity of both varieties increased with increasing moisture content. The sphericity of the paddy grain increased from 37.51 to 38.04% and 34.53 to 35.27% ($P < 0.01$) for Alikazemi and Hashemi varieties, respectively, when the moisture content increased from 8 to 21% (d.b.). It was observed that the sphericity of the Alikazemi variety is more affected by moisture content than is the Hashemi variety. Dutta *et al.* (1988) and Bal and Mishra (1988) considered the grain as spherical when the sphericity value was more than 0.70 and 0.80, respectively. According to obtained results in this study, neither Alikazemi nor Hashemi varieties should be treated as an equivalent sphere for calculation of the surface area. Similar trends of increase have been reported by Reddy and Chakraverty (2004) for raw and parboiled paddy and Yalçın *et al.* (2007) for pea seed.

**Thousand Grain Mass:** The thousand grain mass of paddy increased linearly from 27.63 to 31.20g and 24.43 to 27.80g, respectively, for Alikazemi and Hashemi cultivars, as the moisture content increased from 8 to 21% (d.b.). The effect of moisture content on the thousand grain mass of paddy was significant at the 1% probability level, for both the varieties. As shown in Fig. 7, at all moisture content levels the thousand grain mass of Alikazemi cultivar is more than that of the Hashemi cultivar. A similar increasing trend has been reported by Sacilik *et al.* (2003) for hemp seed and Garnayak *et al.* (2008) for jatropha seed.

**Bulk Density:** The experimental results of the bulk density for paddy grains at different moisture levels are given in Fig. 8. Increasing moisture content had a significant effect ($P < 0.01$) on bulk density of paddy grains by raising it. The bulk density of Alikazemi and Hashemi varieties increased from 433.56 to 476.27 kg/m$^3$ and from 381.77 to 419.81 kg/m$^3$ respectively, as the moisture content increased from 8 to 21% (d.b.). This was due to the fact that an increase in mass owing to moisture gain in the sample was higher than accompanying volumetric expansion of the bulk (Pradhan *et al.* 2008). The results also showed that the Alikazemi variety represented higher bulk density values than the Hashemi variety at all moisture content levels. A similar increasing trend in bulk density has been reported by Baryeh and Mangope (2002) for QP-38 variety pigeon pea and Kingsly *et al.* (2006) for dried pomegranate seeds.

**True Density:** The variation of true density with moisture content for both varieties of paddy grains is shown in Fig. 9. True density of paddy grains at different moisture levels varied from 1405.17 to 1454.93 kg/m$^3$ and 1328.65 to 1364.96 kg/m$^3$ for Alikazemi and Hashemi varieties, respectively. The effect of moisture content on true density of paddy grains showed a significant increase

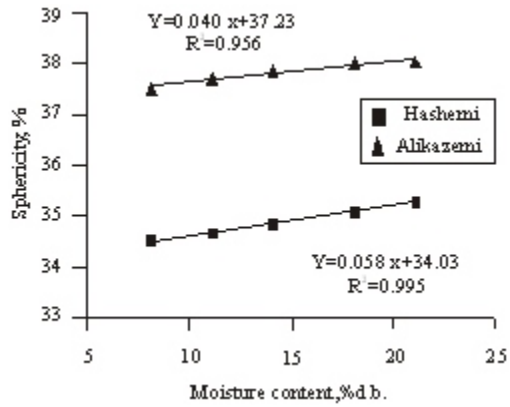


Fig 6: Effect of moisture content on sphericity of paddy grain

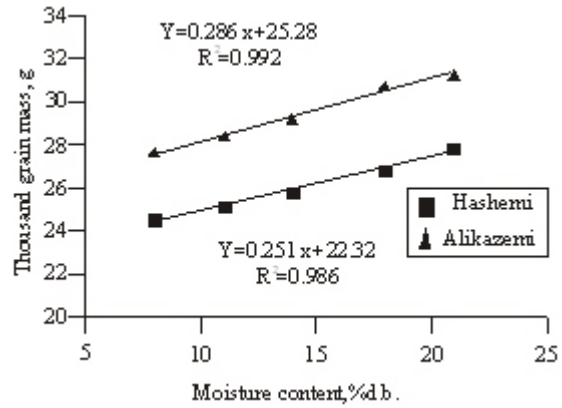


Fig 7: Effect of moisture content on thousand grain mass of paddy grain

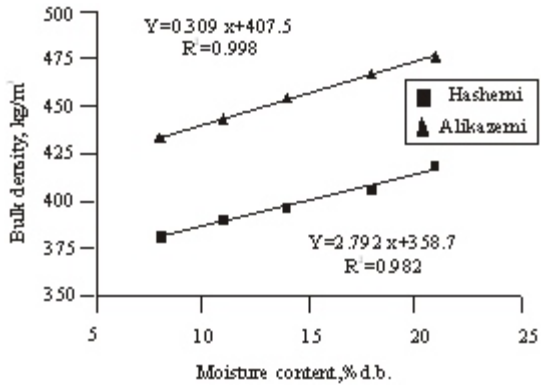


Fig 8: Effect of moisture content on bulk density of paddy grain.

($P < 0.01$) with increasing moisture content. Although the results were similar to those reported by Bart-Plange and Baryeh (2003) for Category B cocoa beans, Coşkun *et al.* (2005) for sweet corn seed, Selvi *et al.* (2006) for linseed and Pradhan *et al.* (2008) for karanja kernel, a different trend was reported by Sacilik *et al.* (2003) for hemp seed and Yalçin *et al.* (2007) for pea seed.

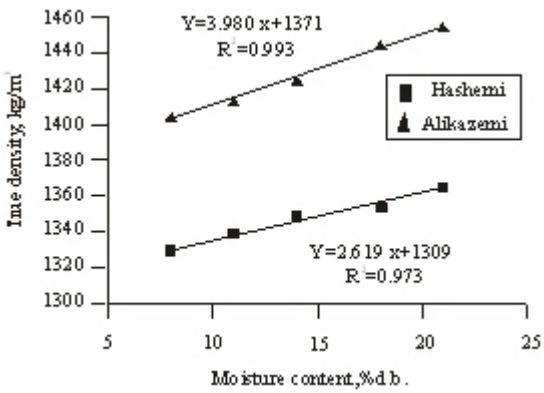


Fig 9: Effect of moisture content on true density of paddy grain.

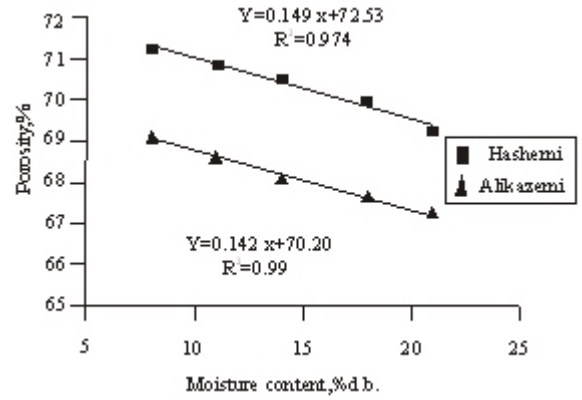


Fig. 10. Effect of moisture content on porosity of paddy grain.

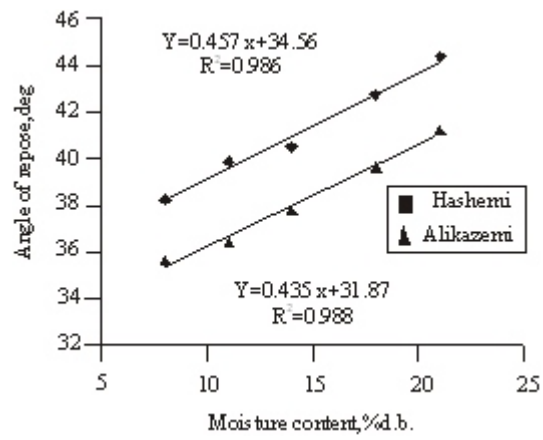


Fig. 11: Effect of moisture content on angle of repose of paddy grain.

**Porosity:** Because the porosity depends on the bulk as well as on true densities, the magnitude of variation in porosity depends on these factors only. The values of porosity were calculated using the data on bulk and true densities of the paddy grains by using Eq. (7) and the results are presented in Fig. 10. The porosity of paddy grains decreased significantly from 69.13 to 67.26% and from 71.26 to 69.24% for Alikazemi and Hashemi varieties, respectively, when the moisture content changed from 8 to 21% (d.b.). The porosity of the Hashemi variety was higher than that of the Alikazemi variety at all moisture content levels. This difference between two varieties could be due to the cell structure, existence of awns and volume and mass increase characteristics of the samples, as the moisture content of grains increases. Sacilik *et al.* (2003) and Kingsly *et al.* (2006) reported similar trends in the case of hemp seed and dried pomegranate seeds, respectively. While Yalçin and Özarslan (2004), Altuntaş and Yildiz (2007), Garnayak *et al.* (2008) and Pradhan *et al.* (2008) reported different trends in the case of vetch seeds, faba bean grains, jatropha seed and karanja kernel, respectively.

**Angle of Repose:** The experimental results for the angle of repose with respect to moisture content are shown in Fig 11. The values were found to increase from 35.67° to 41.23° ($P < 0.01$) and 38.27° to 44.37 ($P < 0.01$), respectively, for Alikazemi and Hashemi cultivars in the moisture range of 8–21% (d.b.). This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the aggregate of grain together by the surface tension (Pradhan *et al*., 2008). These results were similar to those reported by Altuntaş and Yildiz (2007) and Garnayak *et al.* (2008) for faba bean grains and jatropha seed, respectively.

**Static Coefficient of Friction:** Table 2 shows the static coefficient of friction for Alikazemi and Hashemi varieties determined with respect to glass, galvanized iron sheet and plywood surfaces at different moisture content levels. At all moisture content levels, the static coefficient of friction was the highest for both varieties on plywood and the least for glass. The least static coefficient of friction may be owing to smoother and more polished surface of the glass than the other materials used. It was observed that the static coefficient of friction for paddy grains increased significantly ($P < 0.01$) with increasing moisture content on all surfaces. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the grains, offering a cohesive force on the surface of contact. As the moisture content of grains increases, the surface of the samples becomes stickier. Water tends to adhere to surfaces and the water on the moist seed surface would be attracted to the surface across which the sample is being moved. Other researchers found that as the moisture content increased, the static coefficient of friction increased also (Baryeh and Mangope 2002; Altuntaş and Yildiz 2007; Pradhan *et al.,* 2008).

## CONCLUSIONS

- All the physical properties of paddy grain varieties are dependent on their moisture contents.
- As the moisture content of paddy grain increased

Table 2: Static coefficients of friction of paddy grain varieties on various surfaces at different moisture contents

| Variety | Alikazemi | | | Hashemi | | |
|---|---|---|---|---|---|---|
| Moisture content, (%, d.b.) | Static coefficient of friction | | | | | |
| | Glass | Galvanized ironsheet | Plywood | Glass | Galvanized iron sheet | Plywood |
| 8 | 0.3168 (0.0106) a | 0.4179 (0.0084) a | 0.4394 (0.0127) a | 0.3577 (0.0159) a | 0.4629 (0.0085) a | 0.4857 (0.0178) a |
| 11 | 0.3529 (0.0074) b | 0.4377 (0.0098) b | 0.4608 (0.0128) b | 0.3859 (0.0088) b | 0.4766 (0.0097) bc | 0.5087 (0.0091) b |
| 14 | 0.4008 (0.0127) c | 0.4520 (0.0168) c | 0.4788 (0.0167) bc | 0.4315 (0.0114) c | 0.4886 (0.0078) cd | 0.5282 (0.0132) c |
| 18 | 0.4179 (0.0171) d | 0.4694 (0.0205) cd | 0.5013 (0.0160) c | 0.4515 (0.0068) d | 0.4982 (0.0126) cd | 0.5398 (0.0144) c |
| 21 | 0.4369 (0.0087) e | 0.4965 (0.0141) d | 0.5264 (0.0124) d | 0.4650 (0.0055) e | 0.5082 (0.0096) d | 0.5452 (0.0094) d |

Figures in parenthesis are standard deviation. Values in the same columns followed by different letters (a–d) are significant ($P < 0.05$).

from 8 to 21% (d.b.), the average length, width, thickness, equivalent diameter, surface area, volume, sphericity, thousand grain mass and angle of repose increased for both the Alikazemi and Hashemi varieties.

- The bulk and true densities of the both evaluated varieties in this study were observed to increase as the moisture content of grains increased from 8 to 21% (d.b.).
- The porosity of the both varieties of paddy grains decreased with increase in moisture content.
- The static coefficient of friction of both varieties of paddy grains increased linearly with moisture content irrespective of surfaces employed. At all moisture contents, the static coefficient of friction was the highest for both varieties on plywood and the least for glass.

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